HUMAN CAPABILITY-SENSITIVE DESIGN RULES FOR PRODUCTS USING INCLUSIVE DESIGN PRINCIPLES

A Thesis

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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May 2017

Major Subject: Mechanical Engineering

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ABSTRACT

Several design methodologies have been developed that seek to address the diverse needs of disabled users. This work reviews three such methodologies: universal design, design for all, and inclusive design. The core ideas to these methodologies are researched and explained. This work then describes a multitude of state of the art design techniques that utilize these design methodologies, and analyzes two such techniques that are readily applicable in the abstracted, functionally focused design methods that engineers commonly use.

Previous research in inclusive and universal design has led to several sets of inclusive design rules and guidelines. These guidelines suggest modifications to products, environments, and services that could lead to more inclusive redesigns. It would be very beneficial to apply these design guidelines in the initial concept generation process to develop inclusive products; as current accessible design methods rely on expensive specialized modifications to typical products. Preliminary research into these inclusive design rules, and their underlying design representation scheme, has shown that these rules and methods are useful in designing inclusive architectural products. Here, architectural products are defined as products and environments for which the space around the product is important for inclusive design. This work seeks to supplement previous research, and analyze the effectiveness of these design rules when applied to consumer products (i.e. products for which product usability is very important to inclusive design).

This work analyzes sets of inclusive design rules; first by observation, followed by an in-depth case study testing each design rule on a product that was originally designed for users without disabilities. These case studies analyze how inclusive design rules affect products, and what modifications these inclusive design rules lead to. We then study potential users' and experienced designers' opinions regarding the inclusivity of these products in order to gain insight on the effectiveness of the related design rule. The design rules are further analyzed in a second validation study. This validation study tasks participants with redesigning typical products using the given design rules. We analyze how the participants apply the design rules, and what effects they have on product inclusivity.

ACKNOWLEDGEMENTS

I would like to thank all of my family, friends, and colleagues for their support and encouragement throughout my tenure at Texas A&M. I would also like to thank my committee members, Dr. Vinayak and Dr. S. Camille Peres for their support and insights throughout my research.

I would like to acknowledge my committee chair, Dr. Daniel A. McAdams, for being an outstanding advisor. It is because of his aid that I was able to become well-versed in the area of design research. He ensured that I successfully completed my research, and pushed me to uphold a high standard of work.

I wish to thank Amanda Nogay for her belief in me, and for being nothing but supportive through my entire career in graduate school. Finally, I would like to extend a special thanks to my parents for the constant support and the amazing chances that they have given to me over the years.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supervised by a thesis committee consisting of committee chair Daniel A. McAdams, and committee members Vinayak of the Department of Mechanical Engineering and S. Camille Peres of the School of Public Health. All work for the thesis was completed independently by the student.

Funding Sources

This work was made possible in part by the National Science Foundation. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the National Science Foundation.

I would also like to thank the Department of Mechanical Engineering at Texas A&M University for supporting me as both a teaching assistant and research assistant.

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1. INTRODUCTION

More than one billion people in the world report having some level of disability, of whom nearly 20% report having significant disabilities that substantially impact their activities [1]. This number is only expected to grow in the future as the population ages. In general, people with disabilities experience barriers, be they minor or significant, in using products or environments that are designed with typical, or fully-able, users in mind. These barriers often stigmatize the disabled, and can further exacerbate the difficulties in health, financial, or quality of life that disabled people experience. In order to remove these barriers and provide disabled people with opportunities for fulfillment and productivity, it is necessary that we design more inclusive (and ideally universal) products, services, and environments. Here we are defining inclusive design as the practice of designing products to be usable by as many people as reasonably possible, and we are defining universal design as an idealized case of inclusive design in which products are designed for all users, regardless of their ability levels or limitations [2].

The purpose of this work is to aid in creating methods to help engineers practice inclusive design. There are many existing products that are designed to include users with disabilities; most commonly, these solutions involve taking a typical product (i.e. designed for users with no disabilities) and making modifications to adapt the product for disabled use. Adapting typical products is inefficient, as it requires the initial purchase of a typical product coupled with the added time and monetary expenditures for any necessary modifications. Employing inclusive design methodologies in the initial stages of the product design, or redesign, process would be more efficient.

Scope of the Work

Previous research in inclusive design has yielded many different methods and practices for designing more inclusive products. This work focuses on one such method, inclusive design rules, developed by Shraddha Sangelkar [3]. In particular, this work analyzes and validates Sangelkar's inclusive design rules' effectiveness in designing inclusive products. We first performed an extensive review of current practices in inclusive and universal design. We compare these inclusive design rules to similar methods for inclusive design for an initial gauge of their effectiveness. We then combined Sangelkar's rule set with a similar rule set, created by P. John

Clarkson, to add additional insight to the combined rule set. We then analyzed thus combined set of design rules; first by observation, then by an in-depth case study process. These case studies analyze how these inclusive design rules are applied to products in the design process, and provide examples of what modifications these rules may suggest. We then studied the inclusive design rules' effectiveness in designing inclusive products by performing an experimental survey study. Lastly, we further validate these design rules' effectiveness and usability in a second validation study.

2. REVIEW OF STATE OF THE ART INCLUSIVE AND UNIVERSAL DESIGN METHODS

Several design methodologies have been established to help designers better develop products and environments for a wider range of users. This chapter provides a review of current practices in universal design and inclusive design. To better understand how to develop and practice methods for inclusive and universal design, we first review the existing landscape of state of the art inclusive and universal design methodology. By reviewing state of the art methods for inclusive and universal design, we can then compare Sangelkar's inclusive design rules to similar practices and gain initial insight into the effectiveness of these design rules. Additionally, we can provide some validation for the effectiveness of Sangelkar's design rules by comparing them to established inclusive design methods.

Motivation

Inclusive design is a relatively new methodology, brought about by the growing proportion of disabled persons in the population. Elderly persons, and those with disabilities, were largely uncommon dating as recently as the early 20th century. Advancements in medical technology throughout the 20th century have led to an overall increase in the health and well-being of the population [4]. As medical technology improved to support them, the number of elderly and disabled persons grew significantly, whereas the development of disability-friendly products and environments lagged behind.

Disability policy has also evolved over the years. Acts such as the Smith-Fess Act of 1920, and the Social Security Act of 1935 set the framework for providing services to the disabled. Eventually, these policy and technology changes brought about the development of the national standards for barrier-free buildings [5] [6]. Practitioners of barrier-free design realized that designing separate features for disabled access was both expensive and stigmatizing for the disabled. It was also noted that certain changes specifically meant to aid the disabled actually benefited people of all abilities. This realization built the framework for the universal design movement, as engineers recognized that many assistive features could be designed that would aid both disabled and fully abled users [4]. This chapter first reviews the methodologies of inclusive and universal design. We then review advances in the practices of universal and inclusive design, and compares Sangelkar's inclusive design rules to similar practices for a first gauge of their effectiveness.

Review of Universal and Inclusive Design

This section explains the context of this research and its related work. The following subsections describe universal design, design for all, and inclusive design as methodologies, and provide schools of thought related to these methodologies.

Universal Design

Universal design is the engineering practice to develop products and environments in such a way that they can be used effectively by all users without the need for adaptation or specialized design [4]. Researchers also refer to universal design as design for all, accessible design, or inclusive design; although inclusive design is defined differently later in this article. Universal design can be practiced on any product or environment, and there is a wealth of documentation covering the development of universal design techniques over the years.

Development of Universal Design

The term "universal design" was first coined by Ronald Mace, an architect out of North Carolina State University, to describe the methodology of designing products and environments to be usable to the greatest extent possible by all users. Mace was responsible for aiding in the development of the first building code for accessibility in the United States, and his work help lay the foundation for universal design and legislation. In 1989, Mace founded the Center for Universal Design (CUD) at North Carolina State University, which has become an extensive repository of information and research relating to accessible and universal design [4].

Principles of Universal Design

Researchers at the CUD have developed a set of seven principles outlining good practice in universal design. These principles are intended to guide the design process and lead to universal products and environments. The principles are enumerated below [4].

1. Make sure designs are useful and marketable to people with diverse abilities.
2. Ensure designs accommodate a wide range of individual preferences and abilities.
3. Designs should be simple and intuitive to use.
4. Designs should communicate all necessary information effectively to the user regardless of its environment or the user's sensory abilities.
5. Make certain designs minimize the hazards and the consequences of unintended actions.
6. Ensure designs can be used with low physical effort.
7. Designs should provide adequate size and space to accommodate for use, regardless of the user's body size or mobility.

These principles are meant to aid in the design process by providing designers with a set of characteristics that would make products and environments more usable by all. Satisfying all, or even some of, these characteristics would lead to products that are more usable by as many users as possible.

Design for All

Design for all is a methodology found mostly in Europe, and its tenets are nearly identical to those of universal design. The philosophies behind design for all and universal design are very nearly the same, and the terms are often used interchangeably. Both methodologies strive for the design of products and environments that are usable by everyone, regardless of their level of ability.

The methodology behind "design for all" aims for the development of products, environments, services, and information such that it is accessible and convenient for all members of society to use. In practice, design for all leverages the analysis of human needs and the involvement of end users throughout the entire design process [7].

Guidelines for Design for All

The Design for All Foundation has come up with a set of guidelines for design for all, similar to the universal design guidelines from the CUD. To be classified as good practice in design for all, products or environments should satisfy these guidelines [8]:

1. Respectful: The design should respect the diversity of its users.
2. Safe: The design should be free of risks to all users.
3. Healthy: Design should not constitute a health risk or exacerbate problems from illnesses or allergies.
4. Functional: Design should carry out its intended function without any problems or difficulties.
5. Comprehensible: The design should provide clear information, and have coherent spatial distribution and orientation.
6. Sustainable: The design should not misuse resources so that future generations will have same opportunities.
7. Affordable: All users should have the opportunity to enjoy the product.
8. Appealing: The product should be socially acceptable.

Inclusive Design

Designing a product to be truly universal is a difficult task. Due to the sheer size of the population and variation in how disabilities manifest, any design will likely exclude some set of users, no matter how universal it was designed to be. It is generally accepted that it is not always possible to design one product that meets the needs of the entire population [9]. In these cases, the design methodology more similarly reflects that of inclusive design. Here, inclusive design is defined as the design of products that are usable by as many people as reasonably possible [10].

Inclusive Design in Practice

In a product design context, inclusive design centers on developing products that can be used effectively by as many users as possible. Aside from the social impact of including more people, inclusively designed products also have an economic impact; the more inclusive a product is designed to be, the larger its target market is.

While the goal of inclusive design is to include as many users as possible, it does not suggest that a one-size-fits-all solution is appropriate or effective in all situations. In certain scenarios, designing a product to be accessible to people with certain types of disabilities can make it significantly harder to use for fully abled users, or users with a different type of disability [11]. Instead of a one-size-fits-all solution, inclusive design often seeks to account for user diversity through developing flexible or adaptable products or environments.

Dimensions of Inclusive Design

The Inclusive Design Research Centre at OCAD University has developed a set of three dimensions of inclusive design. These dimensions detail what constitutes good practice in inclusive design, and seek to guide the designers in an effort to develop more inclusive systems [12].

1. Recognize Diversity and Uniqueness. Good inclusive design accounts for the diversity of each individual user. As the population continues to grow more diverse, designing products for the 'average' user is becoming not an acceptable solution. All individuals stray from the average in some way, and products should account for this. In practice, flexible or adaptable systems best account for user diversity. These flexible solutions do not imply a separate, specialized solution for each user; but rather a design system that can adapt to the needs of each individual.
2. Inclusive Process and Tools. The design process should include diverse perspectives to mirror the diverse population that products are designed for. To support this diverse participation in the design process, the related design tools should in turn be as accessible and inclusive as possible.
3. Broader Beneficial Impact. Inclusively designed products often have beneficial impacts outside of the context that they were designed for. For example, curb-cuts were originally designed to aid wheelchair users getting on sidewalks, but also benefit a wide number of fully abled users, and are thus nearly ubiquitous now. Inclusive design should build upon this so-called 'curb cut effect', and attempt to leverage inclusive designs to reach more a more diverse range of users.

Summary of Methodologies

All three methodologies – universal design, design for all, and inclusive design – strive to include more diverse user sets when designing products. Inclusive design can be viewed as a more pragmatic case of universal design, or design for all, as it is recognized that it is not always possible to develop a single universal solution that meets the needs of the entire population [7]. Due to the ever-growing number of people that are limited either through age or disability, these methodologies are becoming increasingly important in the design of modern products and environments.

Inclusive and Universal Design Methods

There are a wealth of institutions practicing inclusive and universal design. These institutions provide excellent resources detailing different methods for inclusive and universal product design. We first begin by introducing Sangelkar's inclusive design methods, namely actionfunction diagrams and inclusive design rules, which are the focus of this work. This section then details several state of the art universal and inclusive design practices.

Sangelkar's Methods: Actionfunction Diagrams and Inclusive Design Rules

When designing consumer products, designers should utilize a user-centric process. Design methods that are focused on the user in the early stages of design lead to a more inclusive end product. Modeling the interactions between prospective users and products allows designers to better understand how to design for their target user group's needs and capabilities. Sangelkar, from Texas A&M University, has developed the concept of actionfunction diagram modeling, which incorporates user activities and product functions in a single model, which can then be leveraged for more thoughtful and inclusive designs [3].

Actionfunction Diagram Modeling

Actionfunction modeling combines a functional model and an activity diagram into a single model that characterizes the user-product interaction expected in a designed product. Functional modeling has long been a staple in engineering design, as subdividing a product into its elementary functions allows designers to focus on one product function at a time. Functional diagrams abstract a product's functionality from the product's overall shape or form, allowing designers to remain solution neutral in the early stages of design. In this context, product functions are classified using the Functional Basis [13]. An example functional model of a can opener, taken from Sangelkar's research, is shown in Figure 1 [3].

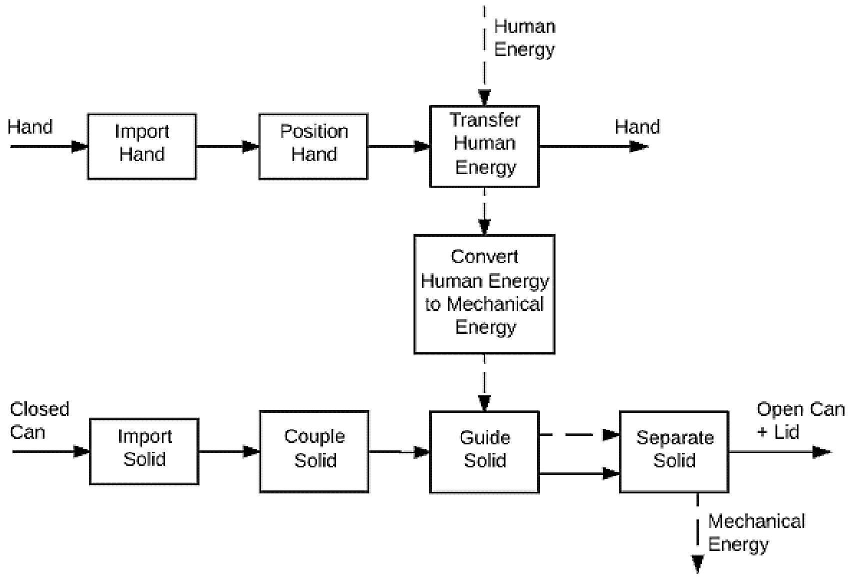


Figure 1. Function Structure for Typical Can Opener [3]

An activity diagram characterizes the user activities involved when interacting with a product. An activity diagram helps to ensure that designers are cognizant of the user's activities, and thus their needs, throughout their interaction with the product [3]. To classify user activities in a clear and repeatable manner, the researchers use the International Classification of Functioning, Disability, and Health (ICF) lexicon [14]. An example activity diagram of the same can opener is shown below.

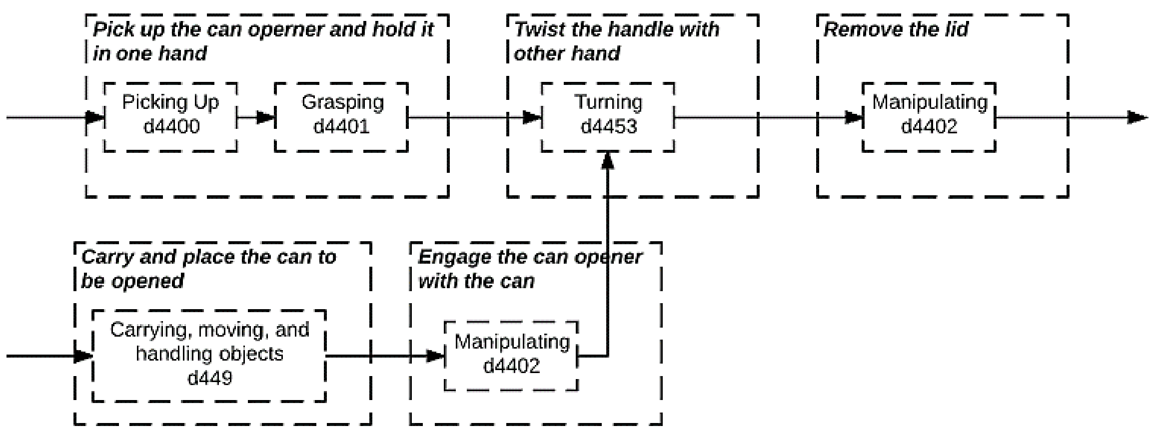


Figure 2. Activity Diagram of Typical Can Opener [3]

One disadvantage to the activity diagram approach is that activity diagrams stand alone from a product's functionality - changes in product functions will not necessarily be reflected by changes in user activities. Actionfunction diagrams incorporate product functions with their respective user activities, overcoming the drawbacks of the activity diagram and providing a powerful tool in modeling the interactions between a product and its user. Actionfunction diagrams are created by superimposing the relevant user activities on their corresponding product functions. An example actionfunction diagram is shown below.

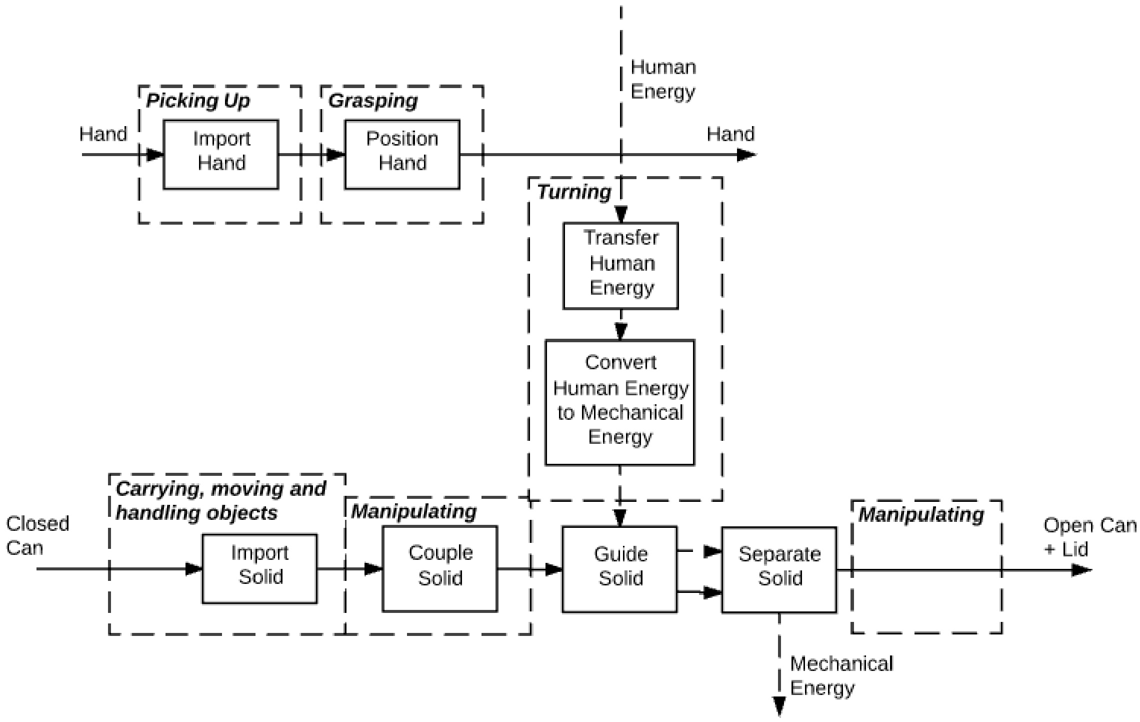


Figure 3. Actionfunction Model of Typical Can Opener [3]

Inclusive Design Rules

There is a wealth of information on product functions that designers can leverage from existing inclusive solutions. By comparing the similarities and differences between typical, non-inclusive, products and products that are viewed as inclusive, designers can track what modifications lead to more inclusive products. Utilizing graph theory and association rule mining, Sangelkar has developed a technique to mine inclusive design rules from product pairs [3]. By comparing the actionfunction models of a typical product and its inclusive counterpart, Sangelkar has developed design heuristics tracking the differences between typical and inclusive products. Changes in user activity or product function are noted as either functional, morphological, or parametric changes. A functional difference between a typical and an inclusive product indicates the addition or deletion of a product function. A morphological difference indicates the two products retain the same functionality, but have a different physical solution. A parametric difference refers to two products that have the same set of parameters, but a differing value for some parameter. Association rule mining and techniques are applied to the tabulated changes, thereby generating design heuristics for more inclusive products. These design rules take the form:

(Typical Product Function, Typical User Activity) → (Change, Inclusive User Activity),

and can be used in conjunction with an actionfunction model of a typical product to suggest changes that will lead to a more inclusive product [3]. These design rules can be thought of as an if-then statement. In other words, if the product contains the (Typical Product Function) coupled with the (Typical User Activity), then make the suggested change; and that change may lead to a more inclusive activity as denoted by (Inclusive User Activity). In the case where a new user activity is not specified, the 'Inclusive User Activity' component is left out. The following figure shows the comparison between the actionfunction diagrams of a typical and inclusive can opener, which highlights the differences between the two product's structures. These differences are then analyzed and developed into inclusive design heuristics (Table 1).

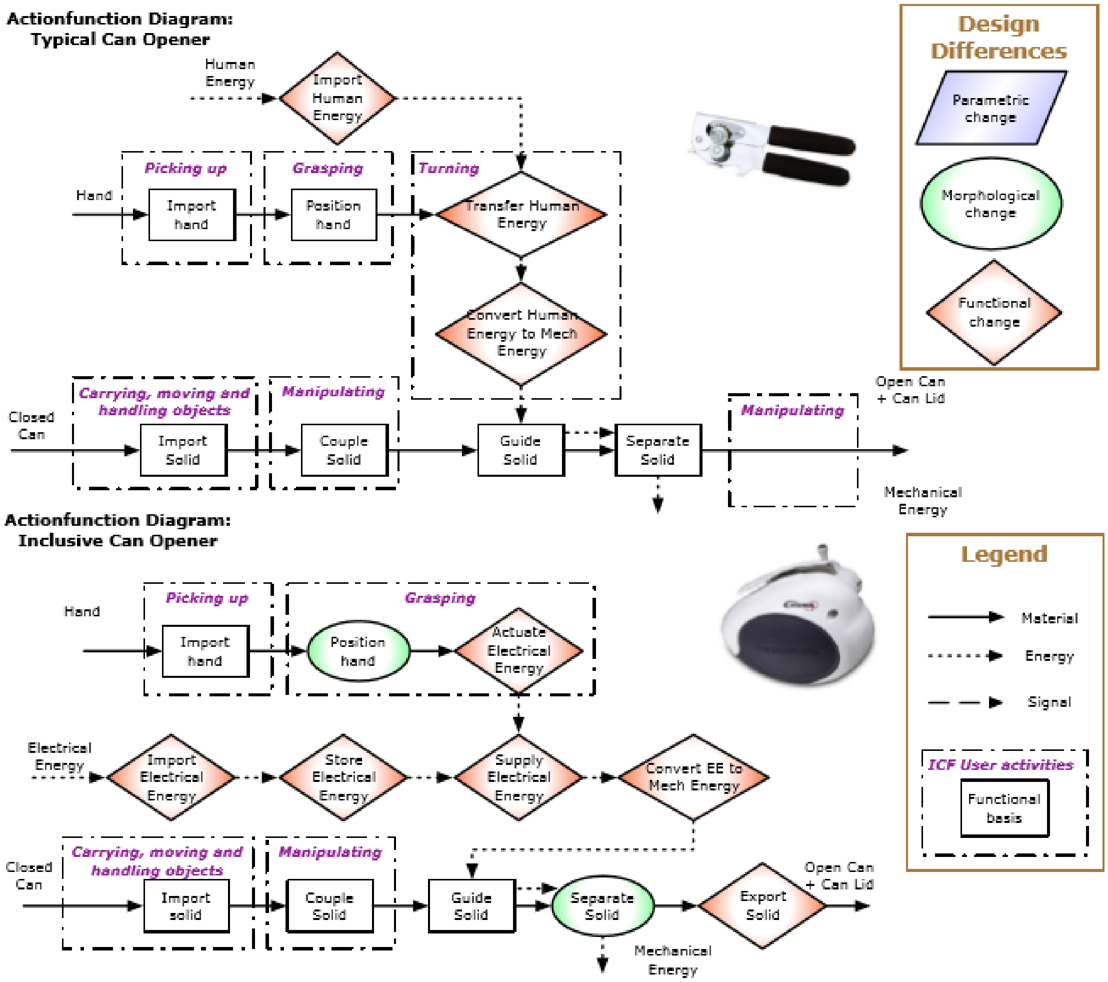


Figure 4. Modified Actionfunction Diagram Using Sangelkar's Design Rules [3]

The actionfunction diagram method and associated design heuristics have been tested through exploratory and validation studies, and show to be an effective tool in increasing the awareness of inclusive design. These inclusive design rules were mined from a large set of product pairs, which are pairs of a typical product and a similar inclusive product. These rules track the differences between typical products and similar, more inclusive products, and suggest changes that would make products more inclusive. A full set of design rules mined from actionfunction diagrams is shown in Table 1 [3].

Table 1. Sangelkar's Inclusive Design Rules [3]

User Activity	Product Function	Recommended Change	User Activity Change
Hand Activities			
Carrying, moving and handling objects	Import Solid	No change	Same as Typical
Carrying, moving and handling objects	Position Hand	Parametric	Easier
Carrying, moving and handling objects	Position Solid	Parametric	Easier
Picking up	Import Hand	No change	Same as Typical
Picking Up	No Function	No change	Same as Typical
Grasping	Position Hand	Parametric	Easier
Grasping	Secure Hand	Functional	Easier
Manipulating	Actuate Signal	Morphological	Pushing with fingers
Manipulating	Guide Solid	Parametric	Easier
Manipulating	Guide Solid	Morphological	Pushing with fingers
Manipulating	Position Hand	Parametric	Easier
Manipulating	Separate Solid	No change	Same as typical
Manipulating	Store Solid	No change	Same as typical
Manipulating	No function	No change	Same as typical
Manipulating	Couple Solid	Parametric	Easier
Pulling	Guide Solid	Parametric	Easier
Pulling	Guide Solid	Morphological	No activity
Pushing with hand	Guide Solid	Parametric	Same as typical
Pushing with fingers	Guide Solid	Parametric	Same as typical
Reaching	Position Hand	Parametric	Easier
Reaching	Import Hand	No change	Same as typical
Reaching	No function	No change	Same as typical
Turning	Guide Solid	Morphological	Pushing with hand
Turning	Regulate Electrical Energy	Parametric	Pushing with fingers
Communication			
Communication written	Indicate Status	Parametric	Easier
Communication written	Indicate Status	Morphological	Communication Braille
Hearing functions	Indicate Status	Parametric	Easier
Hearing functions	Indicate Status	Morphological	Easier
Seeing functions	Indicate Status	Parametric	Easier
Seeing functions	Indicate Status	Morphological	Easier
Gross Body Movements			
Moving around	Import Human	Parametric	Easier
Moving around building other than home	Import Human	No change	Same as typical
Moving around	Secure Human	Functional	Better
Gross Body Movements, continued			
Maintain Body Position	Position Human	Parametric	Easier
Transferring oneself	Import Human	Morphological	Better
Transferring oneself	Import Human	Parametric	Easier
Pushing with lower extremities	Guide Solid	Morphological	Pushing with hand
Sitting	Guide Human	Functional	Better, grasping with hand
Standing	Guide Human	Functional	Better, grasping with hand

User Capability Studies

In order to best design a product to minimize exclusion, one must consider the demands on a user's capabilities. Any user who cannot meet the capabilities demanded by a certain product is severely limited in, if not entirely excluded from, its use. Designers should consider what capabilities their designs demand from users, so as to include as many users as possible. There are several existing inclusive design techniques that leverage data on user capabilities to inform designers of the demands and challenges that certain user sets might experience when using a product or environment.

Human Capability Design Guidelines

Anthropometric data is useful in classifying and comparing human body measurements, such as height or weight. Coupling this data with functional measures, such as reach or dexterity, provides a useful measure on user capabilities. The distribution of these data in a population generally follows a bell curve shape, and it is common practice to design for the middle 90% of a given population. This approach then excludes the outlying lower- and upper- 5% groups from the designed product or environment [15]. Inclusive design is more often associated with disability rather than body dimensions; however, users that are excluded from using a product because of their height are excluded all the same as those who are excluded due to disability. Leveraging anthropometric data's insights on capability would allow designers to develop more inclusive products. Similarly, there are many studies on human capability that can inform designers of the range of abilities, such as sensory or mobility capabilities, which their target user groups possess. Clarkson, of the University of Cambridge, has coupled human capability and anthropometric data in order to develop a set of guidelines for more inclusive design [15].

Table 2. Clarkson's Design Guidelines [15]

Index	**Guideline**
Visual Design Guidelines	
V-1	Attempt to make text as large as possible within the constraints of the design, and maximize the contrast between foreground text and the background.
V-2	Where possible use sans-serif fonts (such as Arial) at larger text sizes with plain instead of patterned backgrounds to increase clarity.
V-3	Avoid the use of decorative and cursive font styles (for example, fonts that mimic handwriting) in favor of clearer, more legible, sans-serif typefaces.
V-4	Attempt to make graphical symbols as large and clear as possible within the constraints of the design.

Table 2. Continued

Index	Guideline
V-5	Attempt maximum contrast between product parts (such as buttons, keys and other controls) against the product body within the constraints of the color palette chosen for a design project.
V-8	Keep the different forms of color blindness in mind when choosing the color palette for a design project. If red and green are to be used together, try to provide an alternative clue (such as a text description) as to what the lights mean.
V-7	Attempt to avoid shiny and highly reflective surfaces that increase the likelihood of glare problems, using materials with matte finishes where possible.
V-8	Reduce glare by positioning light sources away from the user's line of sight and by using shielding or diffusers on light sources.
V-9	Consider providing adjustable light sources (such as lamps) to allow different users to set the lighting environment to their needs.
V-10	Reduce glare and angle of view problems by providing displays and screens that can easily be repositioned.
Hearing Design Guidelines	
H-1	Make volume levels adjustable if possible and try to ensure that frequencies of sound are in the range 800 to 1000 Hz.
H-2	Avoid synthesized speech in favor of natural speech (recorded) if possible, and use lower pitched voices in preference to higher pitched voices.
H-3	Attempt to provide alternative feedback (such as visual or tactile) for people with very low hearing ability and facilitate connections with auditory aids.
H-4	Design environments and spaces to minimize background noises, sound reflection, and reverberation as much as possible to ensure clarity of sound transmission
H-5	Attempt to ensure that when sounds of high pitch are used, they are of a long duration to maximize detection.
Communication Design Guidelines	
C-1	Ensure the areas that the user can interact with, and the correct way to interact with them, are obvious from the overall form of the device.
C-2	Ensure that an uninitiated user can form a correct mental model of how the controls will affect the product and provide positive feedback so that the user can ascertain when their actions have been successful.
C-3	Ensure that the current state or mode of the device is obvious and avoid unnecessarily high demands on user capabilities during product interaction.
C-4	Provide helpful assistance in the event that the user has performed an incorrect action, detailing why their action was unsuccessful and what options are available
C-5	Minimize the adverse consequences when errors or mistakes do occur and ensure all actions are reversible.
C-6	Provide the potential for information to be transferred by different modes, such as textual, verbal, pictorial, tactile, lights and sounds.
Thinking Design Guidelines	
T-1	Avoid overloading memory by reducing the number of simultaneous chunks that are presented at any time.
T-2	Try to minimize the levels of hierarchy used in any menu system and ensure that the current location within the overall hierarchy is always obvious
T-3	Avoid the need to scroll a screen to obtain more menu items and provide a ‘back-up’ button to aid menu navigation, ensuring it is as obvious as the ‘select’ button.
T-4	Consider the use of tabbed interfaces to provide a distinction between different levels of hierarchy, and a map of the current location within the hierarchy; drop down menus do not provide such distinction.

Table 2. Continued

Index	Guideline
T-5	Use shapes, colors and alignment to group alike buttons and displays into chunks, thereby reducing the time and working memory required to locate a desired feature.
T-6	Align controls in a spatial orientation that matches the objects they affect, minimizing the spatial transformations (for example, rotation) required for interpretation.
T-7	Ensure that the control needed is immediately obvious from each device, and that the device that will be affected is immediately obvious from each control.
T-8	Avoid unnecessary demands for time pressure in product interaction.
T-9	Ensure that attention is only required to be directed in one place at any one time.
T-10	Support learning by immediate feedback on any action and ensure all actions are easily and immediately reversible.
T-11	Provide error messages to guide the user to fix the problem.
Locomotion Design Guidelines	
L-1	Attempt to provide adequate space for access and egress when designing doorways, entrances, and exits.
L-2	Consider the use of locomotion aids such as walkers, wheelchairs, and scooters in setting the dimensions of doorways, entrances and pathways.
L-3	Provide adequate seating at regular intervals in public spaces such as parks, airports, and shopping centers.
L-4	Furniture, shower, and toilet design should assist actions such as sitting down, standing up, getting in and out, by providing grab bars, handles or other means of support.
L-5	Design items such as seats, showers, and toilets to assist actions such as sitting down and standing up, or getting in and out, by providing grab bars, handles or other means of support.
L-6	Attempt to integrate grab bars and handles into the overall aesthetic appeal of the design and avoid designs that look ‘medical’ or ‘assistive’.
L-7	Reduce the need to bend the back or reach below waist level for any product interaction.
Reach and Stretch Design Guidelines	
R-1	Allow for single-handed operation where possible, by eliminating the need to reach both hands out simultaneously, and facilitating the option to reach either the left or right arm out to operate a product.
R-2	Ensure that products or services that require access by the public are able to cope with the range of heights that people can reach to, including those in wheelchairs.
R-3	Minimize the need to exert forces with the arms outstretched or, in particular, when reaching over the head.
R-4	Consult available data sources on reach ranges when setting the dimensions of products and environments.
Dexterity Design Guidelines	
D-1	Consider the compatibility of grip and intended action on the product, to avoid situations where a product requires a certain type of grip or motion that is not compatible with the overall task.
D-2	Attempt to lower all force requirements to operate the product controls (grasping, pushing, pulling, twisting and lifting forces), making allowance for older people and people with disabilities who generally have reduced strength compared to younger and fully able people.
D-3	Avoid, where possible, controls that require simultaneous manipulations such as pushing and twisting at the same time, such as those often used with dials and bottle caps.
D-4	Utilize pushing in preference to rotating, since for the latter a pincer grip is required in addition to the application of rotational force.
D-5	Cover surfaces to be gripped with materials that result in adequate friction between the surface of the product handle and the hand, since slippery or smooth surfaces are more difficult to grasp, whereas rubbery and slightly deformable surfaces are easier and more comfortable to hold.

Impairment Simulation

Designers often generate ideas based on their personal experience, using their personal capabilities as a baseline. Unfortunately, this leads to designs that are accessible to some, but exclude others. One method that seeks to alleviate this issue is impairment simulation. Using specialized equipment, designers can simulate the capabilities of individuals with varying types of impairments. Simulation gloves allow designers to experience dexterity and strength impairment in their hands. Similarly, arm or leg braces can allow designers to experience mobility and reach impairments. Leveraging this insight allows designers to consider a wider range of human capabilities when developing products and environments.

Product Family Design

Product family design is often used to develop inclusive solutions to typical products. Product families allow designers to develop a common platform that can be modularized to reach a larger range of user groups. This methodology allows for mass customization of products, which when coupled with inclusive design, would allow designers to provide a wide range of products that encompass all users, regardless of their level of ability. There is a wealth of research in the field of inclusive and universal design that focuses on inclusive product family design [16] [17].

Product Modularity

Moon and McAdams have developed several methods to create universal product families and make decisions regarding these product families [16]. The core of the product family approach is its modular architecture. The module based product family approach allows designers to develop universal product families that consist of three modules: universal modules (that serve both abled and disabled users), accessible (or inclusive) modules, and typical modules (for fully abled users). Figure 5 provides a descriptive diagram of how these modules form a product family [16].

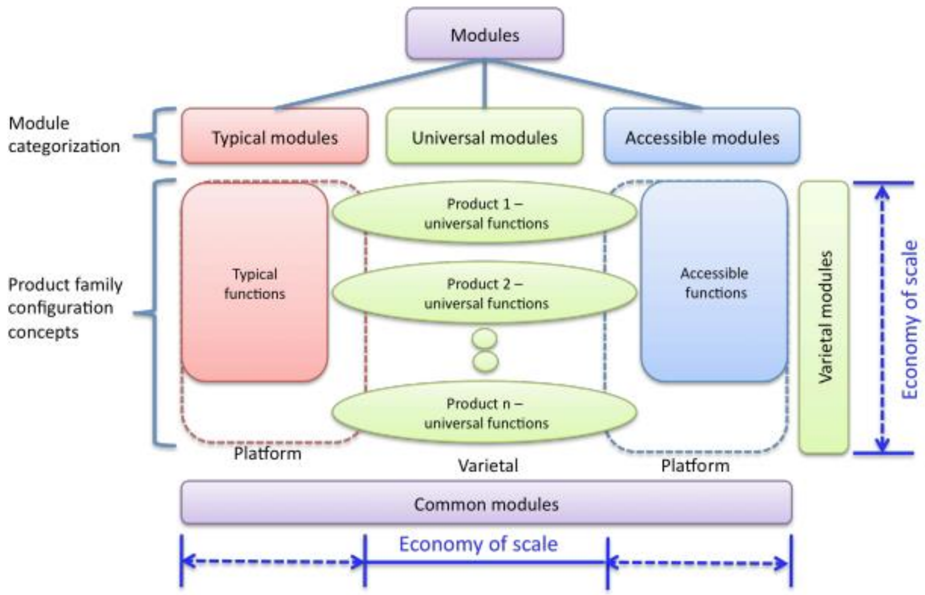


Figure 5. Categorization of Product Modules in Product Family Approach [16]

This universal product family approach, outlined by Moon, utilizes a Bayesian game technique for decision-making and determining strategy in uncertain market environments. This technique facilitates universal product family design by aiding in the determination of trade-offs in platform configurations. This allows designers to select the appropriate product modules to form their desired product family [16].

Product Family Data Mining

In order to develop an optimal product architecture for a product family, Tucker has developed a data mining technique that analyzes customer requirements and the related engineering capabilities [18]. This data mining technique can utilize customer needs surveys, product performance metrics, and cost metrics of varying product module architectures to determine the optimal product family, referred to as a portfolio, for inclusive design. This method combines customer focused objectives and engineering design objectives in developing a proposed product family that optimally satisfies both objectives [18].

Accessibility Standards

Through extensive user test studies, designers have compiled databases of accessible design standards. These databases are intended to aid other designers by providing suggestions for common solutions and dimensions that would lead to more inclusive products and environments.

Accessibility in Architecture

As previously mentioned, the concept of universal design first began with the recognition that environments should be designed to be accessible to all users. The US Department of Justice has published several sets of design regulations in accordance with the Americans with Disabilities Act (ADA) [19]. These regulations set minimum requirements for facilities that seek to promote accessibility for users of all ability levels. These regulations extensively detail many considerations that designers must take when designing structures.

Many institutions have leveraged these policy-mandated regulations alongside results from user studies to develop databases of design suggestions for inclusive architectures. The Center for Inclusive Design and Environmental Access (IDeA) at SUNY Buffalo has developed a design tool, isUD, which provides design practices and suggestions for better, more universally designed environments [20]. Their current tool focuses on the design of universal buildings, and the IDeA plans on expanding this database to include solutions for products and services.

The Center for Accessible Housing, now known as the Center for Universal Design (CUD), at North Carolina State University first began their universal design work in the field of architecture and accessible housing. As part of their research, the CUD published the Accessible Stock House Plans [21]. These housing plans incorporate the principles of universal design in order to make the environments accessible to people who use wheelchairs or other mobility aids. Designers can leverage this resource and the suggestions it provides in order to thoughtfully design environments that are usable by everyone.

Web Accessibility Initiative

The Web Accessibility Initiative (WAI) is an organization focused on accessibility standards for web design. The WAI seeks to provide resources to help make the web accessible to users with disabilities. The WAI is a collaborative initiative that utilizes public interest to help generate standard practices for good web design. These standards focus on developing web content that is [22]:

1. Perceivable: Information must be presentable in ways that all users can perceive. Information cannot be invisible to all of a user's available senses.
2. Operable: Users must be able to easily perform the actions required to operate the system.
3. Understandable: Information and operation should be easily understandable.
4. Robust: Content must be robust enough to be interpreted by a wide range of users, including those who use assistive technology.

The WAI has developed a testable set of requirements that can be used to determine whether or not certain content satisfies the accessibility standards [22]. Even though the WAI technical standards are focused on the development of accessible web content, they provide a wealth of information that is useful in the development of inclusive physical products. These standards can be used to aid in the development of any product that conveys information to the user. By making software, and physical products, that convey information in a clear and understandable format, designers can include a larger number of potential users.

Comparing Sangelkar's Design Rules to Inclusive Design Methods

There are many different inclusive, universal, and design for all methods that cover a wide range of concepts in design methodology. The work of IDeA at SUNY Buffalo primarily focuses on architectural work (i.e. the design of inclusive environments and buildings). The CUD at North Carolina State University deals with both architectural work and high-level philosophical work in inclusive design. Accessibility standards provide suggestions for common solutions that would lead to more inclusive products and environments. Engineering disciplines commonly utilize an abstracted, functionally-oriented approach to design (decomposing a product into its basic functions and developing concepts from the functional model). Sangelkar's methods were developed in a functionally-oriented format, and as such are readily applicable in the abstracted, functionality-focused approach to design [3]. From the methods reviewed, one additional method seems to lend itself to the abstracted functional modeling design approach: Clarkson's human capability design guidelines [15].

Although not specifically tailored for the actionfunction diagram approach, Clarkson's design guidelines do provide very useful information on user activities and product functions that may limit potential users. In order to compare these two rule sets, and in order more easily apply Clarkson's design guidelines in the functional modeling context, we translate Clarkson's design guidelines into Sangelkar's actionfunction rule format. Additionally, translating design guidelines into the actionfunction rule format provides more insight to the inclusive design rule set. The original design guidelines were based upon preexisting product pairs, so the addition of new rule sets can add insight that may be useful in developing more inclusive solutions for products in the future. This section details the procedures involved in generating new design rules by translating Clarkson's human capability design guidelines into the actionfunction design rule format. This section then covers the procedures involved in, and the insights gained from, comparing the two rule sets.

It should be noted that Clarkson's 'Thinking Design Guidelines' have been omitted from this process. This research focuses on the design of products to be inclusive to users who are physically excluded from using a product. In general, users with the same physical disability are excluded from products in the same ways, thus inclusive modifications would affect the product the same for these users. Cognitive disabilities have a much wider range of effects, and thus users with the same cognitive disability may experience widely different effects from product modifications.

Design Guideline Translation

To properly translate Clarkson's design guidelines, we need to characterize the product functions and user activities that each guideline involves, and what types of changes each guideline suggests. The following details the translation of Clarkson's design guidelines into the Sangelkar's design rule framework. For each of Clarkson's design guidelines, we identify a relevant user activity and potential product function. From there, we identify what type of change (parametric, morphological, or functional) the guideline is suggesting, and whether the guideline suggests a more inclusive user activity. Two examples of this translation process are listed below. The alphanumeric preceding each guideline is that guideline's index identity. The remaining translations can be found in Appendix A.

- (**H-3**): "Attempt to provide alternative feedback (such as visual or tactile) for people with very low hearing ability and facilitate connections with auditory aids".
    - This guideline involves the 'Export Signal' function. The relevant ICF user activity is 'Hearing Functions'. Using a different method for providing information entails a morphological change to an alternative perceptual function in terms of user activity.

The resulting design rule is (Export Signal, Hearing Functions) → (Morphological, Alternative Perceptual Functions)

- (**D-4**): "Utilize pushing in preference to rotating, since for the latter a pincer grip is required in addition to the application of rotational force".
    - This guideline entails a morphological change, as it recommends modifying 'Guide Solid' functions that involve the user activity of 'Turning', so as to instead utilize the 'Pushing' user activity, which allows for an easier grip. The resulting design rule takes the form (Guide Solid, Turning) → (Morphological, Pushing).

Clarkson's guidelines are focused on the human user and not the product's functionality, therefore multiple guidelines reference the same product function and action. Duplicate rules have been pared down to a single rule, and the resulting rule set is tabulated in Table 3, where they are also compared to the rules in Sangelkar's rule set. Sangelkar's rules are compared to Clarkson's design guidelines in Table 4. Rules that are bolded denote rules that are exact matches between the two sets, and rules that are italicized denote rules that are similar between the two sets, but have slight differences in how functions or user activities are worded. Both tables, with the comparisons marked are shown on the next pages.

Table 3. Clarkson's Guidelines Compared to Sangelkar's Design Rules

Index	User Activity	Product Function	Recommended Change	User Activity Change
Dexterity				
D-1	Grasping	Position Hand	Morphological	Easier
D-2	Carrying, Moving, And Handling Objects	Transfer Human Energy	Functional	Easier, lower force
D-3	Manipulating	Guide Solid	Morphological	Easier, one application of force
D-4	Turning	Guide Solid	Morphological	Pushing with hand
D-5	Grasping	Secure Hand	Functional	Easier
Reach And Stretch				
R-1	Reaching	Position Hand	Morphological	Reach with single arm
R-2,4	Reaching	Position Hand	Parametric	Easier
R-3	Reaching	Guide Solid	Morphological	Not exerting force with arm outstretched
Locomotion				
L-1,2	Moving Around	Import Human	Parametric	Easier
L-3	Moving Around	Support Human	Functional	Sitting
L-4, 5	Changing Basic Body Position	Support Human	Functional	Grasping with hand
L-6	Moving Around	Support Human	Morphological	Aesthetically better
L-7	Bending	Interface With Product	Morphological	Remove bending
Communication				
C-1	Perceptual Functions	Interface With Product	Morphological	Easier
C-2,3,4,5	Perceptual Functions	Indicate Status	Functional	Easier
C-6	Perceptual Functions	Indicate Status	Morphological	Communication - various
Hearing				
H-1,5	Hearing Functions	Export Signal	Parametric	Change to easier volume/frequency
H-1,5	Hearing Functions	Adjust Signal	Functional	Adjustable Volume
H-2,4	Hearing Functions	Export Signal	Morphological	Easier, Natural Voice
H-3	Hearing Functions	Export Signal	Morphological	Communication - various
Vision				
V-1,2,3	Communication - Written	Indicate Status	Parametric	Easier
V-4,5,6	Communication - Nonverbal	Indicate Status	Parametric	Easier
V-7,8,9,10	Seeing Functions	Indicate Status	Morphological	Easier, reduce glare

(green)	indicates Clarkson rule matches Sangelkar's rule
(yellow)	indicates Clarkson's rule is similar to Sangelkar's rule, but has small difference

Table 4. Sangelkar's Design Rules Compared to Clarkson's Design Guidelines

User Activity	Product Function	Recommended Change	User Activity Change
Hand Activities			
Carrying, moving and handling objects	Import Solid	No change	Same as Typical
Carrying, moving and handling objects	Position Hand	Parametric	Easier
Carrying, moving and handling objects	Position Solid	Parametric	Easier
Picking up	Import Hand	No change	Same as Typical
Picking Up	No Function	No change	Same as Typical
Grasping	Position Hand	Parametric	Easier
Grasping	Secure Hand	Functional	Easier
Manipulating	Actuate Signal	Morphological	Pushing with fingers
Manipulating	Guide Solid	Parametric	Easier
Manipulating	Guide Solid	Morphological	Pushing with fingers
Manipulating	Position Hand	Parametric	Easier
Manipulating	Separate Solid	No change	Same as typical
Manipulating	Store Solid	No change	Same as typical
Manipulating	No function	No change	Same as typical
Manipulating	Couple Solid	Parametric	Easier
Pulling	Guide Solid	Parametric	Easier
Pulling	Guide Solid	Morphological	No activity
Pushing with hand	Guide Solid	Parametric	Same as typical
Pushing with fingers	Guide Solid	Parametric	Same as typical
Reaching	Position Hand	Parametric	Easier
Reaching	Import Hand	No change	Same as typical
Reaching	No function	No change	Same as typical
Turning	Guide Solid	Morphological	Pushing with hand
Turning	Regulate Electrical Energy	Parametric	Pushing with fingers
Communication			
Communication written	Indicate Status	Parametric	Easier
Communication written	Indicate Status	Morphological	Communication Braille
Hearing functions	Indicate Status	Parametric	Easier
Hearing functions	Indicate Status	Morphological	Easier
Seeing functions	Indicate Status	Parametric	Easier
Seeing functions	Indicate Status	Morphological	Easier
Gross Body Movements			
Moving around	Import Human	Parametric	Easier
Moving around building other than home	Import Human	No change	Same as typical
Moving around	Secure Human	Functional	Better
Maintain Body Position	Position Human	Parametric	Easier
Transferring oneself	Import Human	Morphological	Better
Transferring oneself	Import Human	Parametric	Easier
Pushing with lower extremities	Guide Solid	Morphological	Pushing with hand
Sitting	Guide Human	Functional	Better, grasping with hand
Standing	Guide Human	Functional	Better, grasping with hand
(green)	indicates Sangelkar’s rule matches Clarkson rule		
(yellow)	indicates Sangelkar’s rule is similar to Clarkson’s rule, but has small difference		

Comparison of Design Rule Sets

With Clarkson's design guidelines translated to the association rule format, we can directly compare the two rule sets to see if any additional insight can be gained. Clarkson's design guidelines are developed from data on human capability, and provide insight on what user activities people may be limited in when using a product. Sangelkar's design rules are mined from preexisting inclusive solutions, and thus can provide insight on inclusive product functionality.

From this direct comparison, we can divide the rules into three categories, matching rules, similar rules, and non-intersecting rules. Matching design rules are rules that are the exact same between both rules sets. Rules are said to be similar between the two design sets when the user activities and product functions are similar between the two rules, but there may be some difference in terms of proposed change or user activities or functions may be slightly different. For the rules at which both Clarkson's guidelines and Sangelkar's heuristics intersect, we apply the respective changes to the actionfunction structure of a typical product and observe the results. First and foremost, we observe how intuitive it is to apply the design guidelines or heuristics, and whether or not the resulting actionfunction diagram is meaningful. Since Clarkson's design guidelines are based off of human constraints, it is difficult to functionally clarify several design guidelines. It is beneficial to compare these guidelines to their related design rules to determine whether they are effective in the actionfunction diagram approach.

Design Rule Comparison Approach

For each set of matching or similar design rules, we first identify a product on which these rules would be applicable. We develop an actionfunction diagram for the chosen typical product and then apply the inclusive design rules. We then find an existing product that could provide a physical representation of the modified actionfunction diagram. To gauge if the modifications suggested by the design rules are meaningful, we observe the chosen product's inclusivity with respect to the initial typical product.

Comparing Matching Design Rules

As mentioned in the previous section, Clarkson's design guidelines have been translated into the design heuristic format and tabulated in Table 3. There are numerous similarities between the two sets of design rules, with seven exact matches and multiple close similarities between translated Clarkson's human-interaction design rules and Sangelkar's product functionality-based design heuristics. The matching rules are shown in Table 5.

Table 5. Exact Matching Design Rules

Index	Guideline
D-4	(Guide Solid, Turning) → (Morphological, Pushing with Hand)
D-5	(Secure Hand, Grasping) → (Functional, Secure Hand)
R-2,4	(Position Hand, Reaching) → (Parametric, Reaching)
L-1,2	(Import Human, Moving Around) → (Parametric, Moving Around)
V-1,2,3	(Indicate Status, Communication – Written) → (Parametric, Communication – Written)
V-7,8,9,10	(Indicate Status, Seeing Functions) → (Morphological, Seeing Functions)

As these design rules are exact matches in the actionfunction heuristic format, we can assume that applying the matching rules from Clarkson's and Sangelkar's rule sets to an actionfunction diagram will have the same results. These matching rules affect the same functions and user activities in the same ways, which should result in the same changes to the resulting actionfunction diagrams. In order to compare the meaningfulness and effectiveness of the translated design guidelines, we first start comparing these exactly matching design rules. In this section, we provide an example of these comparisons; the remaining comparisons can be found in Appendix B.

- ***D-4: (Guide Solid, Turning) → (Morphological, Pushing with Hand)***

In Clarkson's work, this guideline suggests utilizing the user activity of 'Pushing' instead of 'Turning', as turning a product requires a user to grip with a pincer-like grip as well as apply rotational force. A typical product that requires the turning user activity is a sink. The actionfunction diagram of a typical sink can be seen in Figure 7.

Figure 6. Typical Sink with Turning Knobs

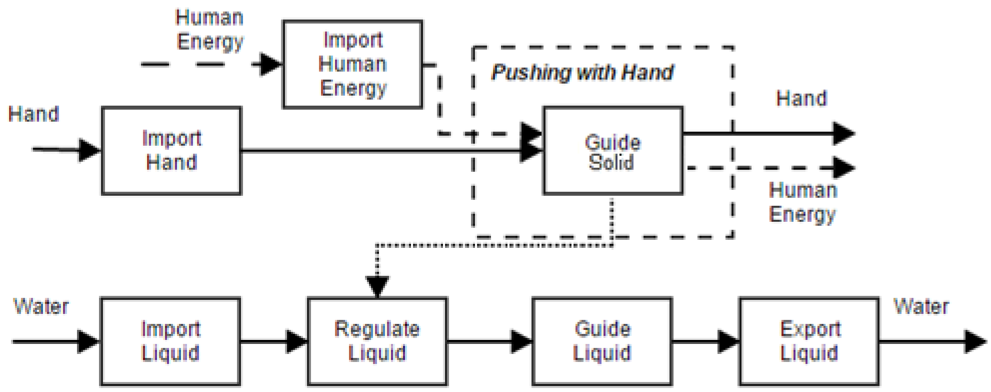


Figure 7. Actionfunction Diagram of Typical Sink

Applying Clarkson's guideline of "Utilize pushing in preference to rotating…", which entails a morphological change to the 'Guide Solid' function under the 'Turning' user activity, we obtain the actionfunction diagram in Figure 8.

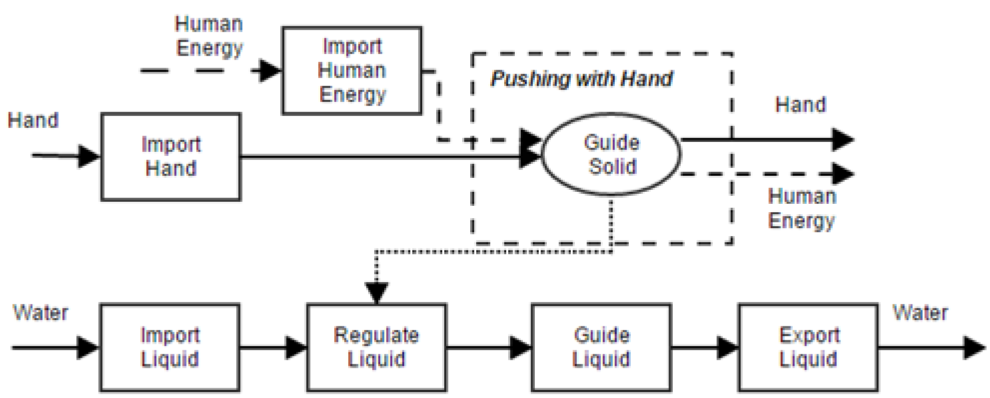


Figure 8. Sink Actionfunction Modified Using Clarkson's Rule

The modified actionfunction diagram of Figure 8 reflects the morphological change to change the 'Guide Solid' user activity from 'Turning' to 'Pushing'. The resultant inclusive actionfunction diagram closely mirrors how sinks with handles function, and thus proves to be meaningful. Sinks with push handles instead of dials allow for an easier actuation of the sink flow, as users need simply push the handle to begin flow of water rather than having to twist a dial.

Pushing is an easier user activity, as it requires less fine motor skills to accomplish than twisting a dial.

Applying Sangelkar's design rule of (Guide Solid, Twisting) → (Morphological, Pushing) to the typical sink yields the same results as applying Clarkson's design guideline. The results of modifying the typical sink actionfunction diagram using the aforementioned rule from Sangelkar's rule set can be seen in Figure 9. Sangelkar's design rule suggests a morphological change to the 'Guide Solid' function in the typical sink actionfunction diagram, signifying to the designer that morphological changes, such as changes to how a user actuates the sink flow, will lead to a more inclusive product.

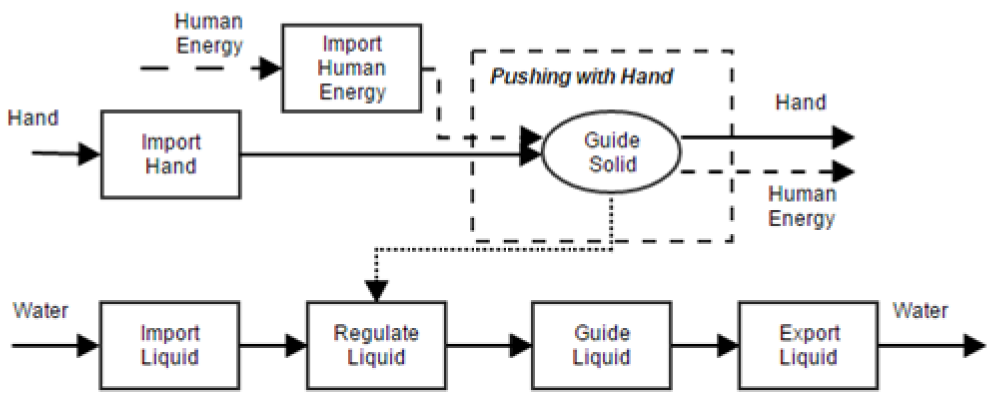


Figure 9. Sink Actionfunction Modified Using Sangelkar's Rule

These resulting actionfunction diagrams closely mirror the functionality of a push button sink faucet, such as the one pictured below. These faucets allow users to actuate the flow of water by pushing down the sink handle, which is easier for many users to accomplish than turning the handle. The action of pushing is more inclusive than turning, as it does not require any sort of grip or gripping strength to accomplish. The modified product, represented by the push button sink in Figure 10, is more inclusive than the typical turning sink dial, and provides a first glance at the meaningfulness of the analyzed design rule.

Figure 10. Modified Sink, Suggested by Design Rules

Comparing Similar Design Rules

Analyzing and comparing the effects of applying matching design rules from each set of design rules allows us to see if each rule has meaning and is effective when applied to an actionfunction diagram. However, comparing matching rules does not allow us to compare the effects of each set of design rules, as matching design rules should, and have been shown above to, have the same effects when applied to actionfunction diagrams. In order to better compare the meaningfulness and effectiveness of these design rules, we instead compare and analyze the rules that do not exactly match. Table 6 pairs the similar design rules from each set.

Table 6. Similar Design Rules

Index	Clarkson's Similar Design Rule	Sangelkar's Similar Design Rule
1.	(Guide Solid, Manipulating) → (Morphological, Easier; one application of force)	Guide Solid, Manipulating) → (Morphological, Manipulating)
2.	(Position Hand, Grasping) → (Morphological, Grasping)	(Position Hand, Grasping) → (Parametric)
3.	(Support Human, Changing basic body position) → (Functional, Grasping)	(Guide Human, Sitting) → (Functional, Grasping) **AND** (Guide Human, Standing) → (Functional, Grasping)
4.	(Indicate Status, Perceptual Functions) → (Morphological, Communication - various) **AND** (Indicate Status, Communication - nonverbal) → (Morphological, Communication - various)	(Indicate Status, Communication – written) → (Morphological, Communication – braille)
5.	(Export Signal, Hearing Functions) → (Parametric)	(Indicate Status, Hearing Functions) → (Parametric)
6.	(Export Signal, Hearing Functions) → (Morphological, Hearing Functions)	(Indicate Status, Hearing Functions) → (Morphological)
7.	(Indicate Status, Communication - nonverbal) → (Parametric)	(Indicate Status, Seeing Functions) → (Parametric)

This section details analyzing the similar design rules. These rules are compared and analyzed by first selecting a product that would relate the chosen rule set. We then create the actionfunction diagram for the selected product and apply each selected design rule. For each modified actionfunction diagram, we select an existing product that can physically represent the actionfunction diagram. In this section, we provide an example comparison; the remaining comparisons can be found in Appendix C.

- ***2. Clarkson: (Position Hand, Grasping) → (Morphological, Grasping) vs. Sangelkar: (Position Hand, Grasping) → (Parametric, Grasping)***

In Clarkson's guidelines, this rule is expressed as a need to "[c]onsider the compatibility of grip and intended action on the product" [15]. A typical product that exhibits actions incompatible with grip is a garlic press. The typical garlic press requires users to squeeze two handles together with enough force to crush garlic. This action requires a large amount of grip strength, and would be difficult for users without full ability in their hands. An actionfunction diagram for a typical garlic press can be seen in Figure 12.

Figure 11. Typical Garlic Press

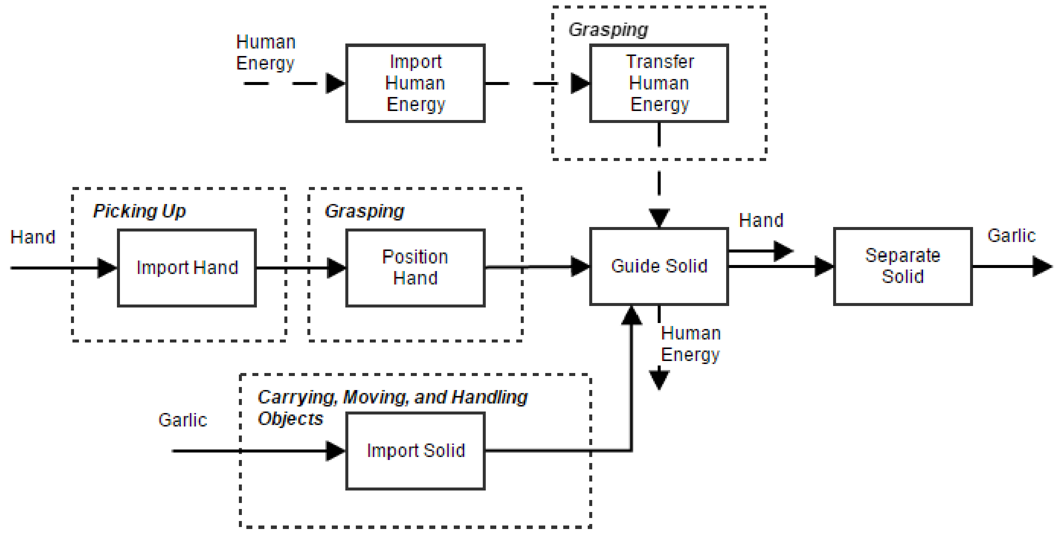


Figure 12. Actionfunction Diagram of Typical Garlic Press

Applying Clarkson's guideline to the typical garlic press entails a morphological change to the 'Position Hand' function under the 'Grasping' user activity, which then leads to a change in the 'Transfer Human Energy' function. These morphological changes modify how the user holds the garlic press and then transfers energy into the system to crush garlic.

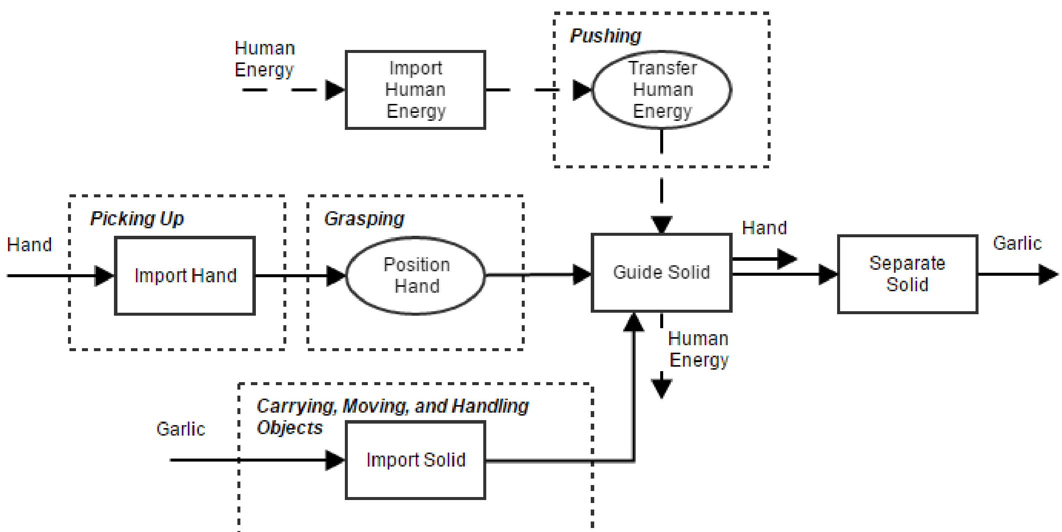


Figure 13. Garlic Press Actionfunction Modified Using Clarkson's Rules

The actionfunction diagram of Figure 13 can be physically represented by a garlic rocker. Garlic rockers eliminate the need for users to squeeze two handles in one hand, as in a traditional garlic press, and instead allow the user to press garlic by pushing the device downward in a rocking motion. A rocking motion would be much easier to accomplish for users with lower hand strength, as it allows the user to instead exert force from the larger muscle groups in their arms. Additionally, the garlic rocker helps to alleviate discomfort for those who experience pain when grasping tightly with their hand by allowing the user to press downwards instead of squeeze with their hands.

Figure 14. A Garlic Rocker, Physical Representation of Clarkson's Changes

Applying Sangelkar's similar guideline to the typical garlic press yields a much different result. Sangelkar's rule entails a parametric change to the 'Position Hand' function under the 'Grasping' user activity, which then leads to a change in the 'Transfer Human Energy' function. These parametric changes modify the size and shape of the garlic press's handle in order to make the grasping motion more comfortable for the user. The resulting garlic press action function diagram can be seen in Figure 15. This alleviates some of the discomfort users experience from squeezing the handles together, but does not make the motion of pressing garlic much easier.

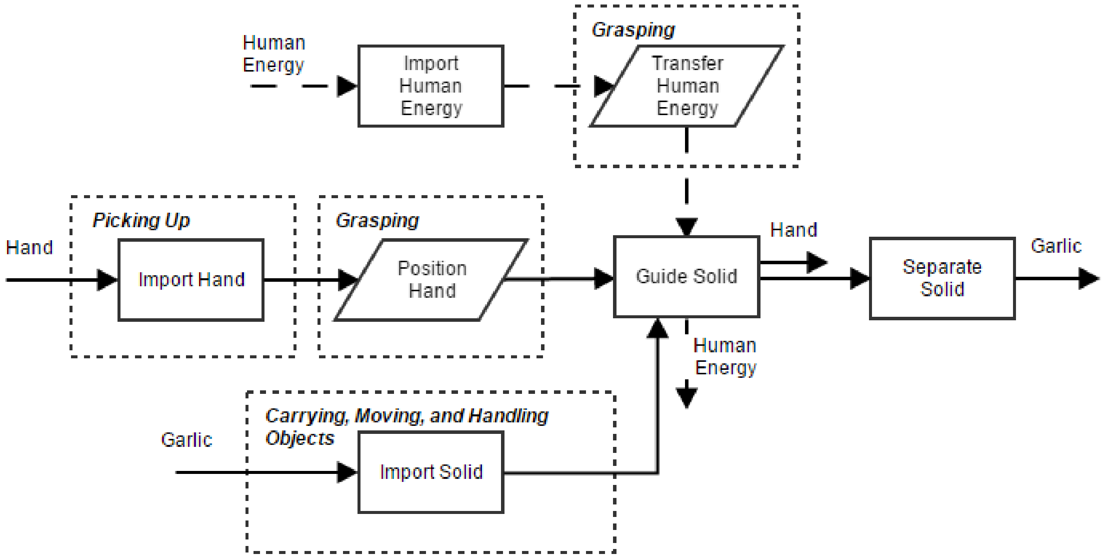


Figure 15. Garlic Press Actionfunction Modified Using Sangelkar's Rule

The parametric changes suggested by Sangelkar's design rule alleviate some of the discomfort users experience from squeezing the handles together, but do not make the motion of pressing garlic too much easier. The resulting modified garlic press, physically represented by the Kuhn Rikon® Garlic Press in Figure 16, fits more comfortably in a user's hand than a typical garlic press with straight handles. The modified garlic press also requires less force than a typical garlic press due to a better lever arm advantage in the handles. However, the Sangelkar-modified garlic press still requires users to squeeze the handles tightly between their hands, an action that is not inclusive for users with weakened hands

Figure 16. Physical Representation of Garlic Press Modified Using Sangelkar's Rule

Applying Clarkson's morphological change yields a more inclusive product with respect to Sangelkar's similar rule of a parametric change in this instance. It may be useful to track whether parametric, morphological, or functional changes lead to more inclusive design rules, all other factors remaining constant.

Conclusions from Comparing Rule Sets

By comparing similar and matching design rules from both rule sets, we gain a first glance at the validity of translating guidelines into Sangelkar's format. First and foremost, we observe how intuitive it is to apply the design guidelines or heuristics, and whether the resulting actionfunction diagram is meaningful. In all cases of similar and matching design rules, the resultant actionfunction diagram appeared to be meaningful, in that each actionfunction diagram can be physically represented as a preexisting product that is more inclusive than the original, typical product. In order to further test the efficacy of these design rules, and thereby determine the validity of translating guidelines into this rule format, we should test each design rule on products for which we are not aware of a preexisting inclusive solution. This distinction will allow us to focus on the changes suggested by the relevant design rules, rather than basing our modifications and solutions on prior knowledge.

Closing Remarks from Review of Current Inclusive and Universal Design Methods

This chapter seeks to provide a review of several existing techniques for practicing inclusive or universal design, to which we compare Sangelkar's inclusive design rules. As the number of disabled, or otherwise limited, users continues to grow, there is an increasingly large need for inclusive and universal products that address these limitations. The concepts of universal design, design for all, and inclusive design discussed in this work seek to provide an increased quality of life for limited users by designing products that are usable by all, or as many as possible, people regardless of their limitations. The methods and practices presented in this article do not make up the whole of all inclusive or universal design techniques, but provide a good representation of currently used techniques.

This chapter also demonstrates and compares two inclusive design practices, Clarkson's human capability design guidelines and Sangelkar's inclusive design rules and actionfunction diagrams. These two methods are readily applicable in the abstracted, functionally-oriented design approach that is common in engineering design. Clarkson's design guidelines provide a human-capability sensitive approach to inclusive design, as the guidelines are derived from anthropometric and human capability data. Sangelkar's actionfunction diagrams provide a standard, repeatable method to represent the user-product interactions involved in a product, and the related inclusive design rules provide a wealth of design modifications mined from preexisting inclusive design solutions. Combining Clarkson's guidelines with Sangelkar's rules allows us to create a single rule set with the combined insights from human capability data and inclusive product pairs. In order to further characterize the effectiveness of these two methods moving forwards, it would be very beneficial to apply each design rule to products for which we are not aware of preexisting inclusive solutions and analyze the resulting changes.

3. HUMAN CAPABILITY-SENSITIVE DESIGN RULES

Previous research into inclusive design has yielded several sets of inclusive design rules and guidelines. One such set, Sangelkar's set of inclusive design rules, is the focus of this research. Preliminary research has shown that Sangelkar's rules are problem dependent in their effectiveness, and have been shown to be effective in designing more inclusive architectural products [3]. Here, architectural products are defined as products and environments for which the space around the product is an important factor in using the product (e.g. buildings, parks). The primary objective of this work is to provide evidence that inclusive design rules are also effective in designing inclusive consumer products. This work analyzes sets of inclusive design rules; first by observation, followed by an in-depth case study testing each design rule on a product that was originally designed for users without disabilities. These case studies analyze how inclusive design rules affect products, and what modifications these inclusive design rules lead to. We then study potential users' and experienced designers' opinions regarding the inclusivity of these products in order to gain insight on the effectiveness of the related design rule. The design rules are further analyzed in a second validation study. This validation study tasks participants with redesigning typical products using the given design rules. We analyze how the participants apply the design rules, and what effects they have on product inclusivity.

The design rules being considered in this chapter are a combination of Sangelkar's actionfunction-inspired inclusive design rules and Clarkson's human capability design guidelines.

Development of Combined Rule Set

As mentioned in the closing remarks of Chapter 2, combining Clarkson's guidelines with Sangelkar's rules allows us to create a single rule set with the combined insights from human capability data and inclusive product pairs. Clarkson's guidelines are focused on human capability and measurement data, and thus provide insight into user activities (in the actionfunction diagram format) that may limit users. Sangelkar's inclusive design rules are derived from comparing inclusive versions of products to their typical counterparts, and thus provide insight on current solutions to more inclusive functions. Moving forwards, we analyze the effects and effectiveness of the rule set formed by combining Sangelkar's inclusive design rules with Clarkson's human capability design guidelines. We call these combined rules human capability-sensitive design rules, and the combined rule set is shown in Table 7.

Table 7. Combined Rule Sets (Human Capability-Sensitive Design Rules)

User Activity	Product Function	Recommended Change	User Activity Change
Dexterity			
Carrying, Moving, And Handling Objects	Transfer Human Energy	Functional	Easier, lower force
Carrying, moving and handling objects	Import Solid	No change	*Same as Typical*
Carrying, moving and handling objects	Position Hand	Parametric	Easier
Grasping	Position Hand	Parametric	Easier
Grasping	Secure Hand	Functional	Easier
Grasping	Position Hand	Morphological	Easier
Manipulating	Guide Solid	Morphological	Easier, one application of force
Manipulating	Actuate Signal	Morphological	Pushing with fingers
Manipulating	Guide Solid	Parametric	Easier
Manipulating	Position Hand	Parametric	Easier
Manipulating	Couple Solid	Parametric	Easier
Pulling	Guide Solid	Parametric	Easier
Pulling	Guide Solid	Morphological	No activity
Pushing with hand	Guide Solid	Parametric	Same as typical
Pushing with fingers	Guide Solid	Parametric	Same as typical
Turning	Guide Solid	Morphological	Pushing with hand
Turning	Regulate Electrical Energy	Parametric	Pushing with fingers
Reach And Stretch			
Reaching	Position Hand	Morphological	Reach with single arm
Reaching	Position Hand	Parametric	Easier
Reaching	Guide Solid	Morphological	Not exerting force with arm outstretched
Locomotion			
Bending	Interface With Product	Morphological	No bending over
Changing Basic Body Position	Support Human	Functional	Grasping with hand
Maintain Body Position	Position Human	Parametric	Easier
Moving Around	Import Human	Parametric	Easier
Moving Around	Support Human	Functional	Add in seating
Moving Around	Support Human	Morphological	Aesthetically better
Moving around	Secure Human	Functional	Better
Pushing with lower extremities	Guide Solid	Morphological	Pushing with hand
Sitting	Guide Human	Functional	Better, grasping with hand
Standing	Guide Human	Functional	Better, grasping with hand
Transferring oneself	Import Human	Morphological	Better
Transferring oneself	Import Human	Parametric	Easier
Communication			
Perceptual Functions	Interface With Product	Morphological	Easier
Perceptual Functions	Indicate Status	Functional	Easier
Perceptual Functions	Indicate Status	Morphological	Communication - various
Hearing			
Hearing functions	Indicate Status	Parametric	Easier

Table 7. Continued

User Activity	Product Function	Recommended Change	User Activity Change
Hearing			
Hearing functions	Indicate Status	Morphological	Easier
Hearing Functions	Export Signal	Parametric	Adjust volume/frequency
Hearing Functions	Adjust Signal	Functional	Adjustable Volume
Hearing Functions	Export Signal	Morphological	Easier, Natural Voice
Hearing Functions	Export Signal	Morphological	Communication - various
Vision			
Communication - Written	Indicate Status	Parametric	Easier
Communication written	Indicate Status	Morphological	Communication Braille
Communication - Nonverbal	Indicate Status	Parametric	Easier
Seeing functions	Indicate Status	Parametric	Easier
Seeing Functions	Indicate Status	Morphological	Easier, reduce glare

Case Study and Experimental Approach

In order to test the efficacy of these design rules, we test each rule on a case by case basis. The goal of this study is to analyze the application of these design rules on consumer products. These cases show in detail the process of applying inclusive design rules to products, and provide examples of what modifications these rules may suggest. For each design rule, we have chosen a relevant typical product and developed an actionfunction diagram. We have also provided information on what difficulties a lesser-abled user may have with the typical product, and what needs that such a user may require. As the purpose of this study is to test the applicability and efficacy of these design rules, we have chosen products for which we have no knowledge of a preexisting inclusive alternative. We have made this distinction so as to avoid basing our modifications and solutions on prior knowledge and instead focus on the changes suggested by the relevant design rules.

Case Studies

For each case in this study, we apply the relevant design rule to the typical product's actionfunction diagram, therefore creating a modified actionfunction diagram that will lead to a more inclusive design. Utilizing this modified actionfunction diagram, we develop and sketch a physical representation of a possible solution. For the cases in which we are applying multiple similar design rules, we develop a physical representation for both solutions and compare the results. The section below details one example of a case study done on the typical light bulb. The remaining 33 cases can be found in Appendix D.

Case 3: Light Bulb

Users with diminished hand strength may have difficulties performing activities that require simultaneous manipulations. A product that requires simultaneous manipulations is a lightbulb, as users must push and turn the lightbulb in order to install it. Typical lightbulbs are installed by pushing and twisting the bulb into a threaded socket, which would be a difficult set of actions to perform for someone with some form of hand impairment. Applying the relevant design rule yields the following, modified, product. In order to make installing a light bulb more inclusive for users who have difficulty performing simultaneous manipulations, we must develop a new method to install and uninstall a lightbulb.

A physical embodiment of this solution is sketched out on the next page. This new method utilizes a special rotating latch mounted to a cage where the bulb sits. To install the light bulb, a user simply needs to push the bulb into the cage until it contacts the electrical contacts. The user continues pushing the bulb after the bulb contacts the electrical contact, thereby depressing the whole bulb-cage assembly. As the bulb-cage assembly is pushed down, it rotates two locking gears that are attached to two capture walls. When the bulb-cage assembly is fully depressed, these two capture walls fully enclose the base of the bulb, and the locking gears lock into position, thereby securing the whole assembly. To uninstall the bulb, a user needs to gently press in on a tab on the side which releases the locking capture walls, after which the user can simply pull the bulb out of the socket. Figure 17 provides an image of what this modified light bulb might look like.

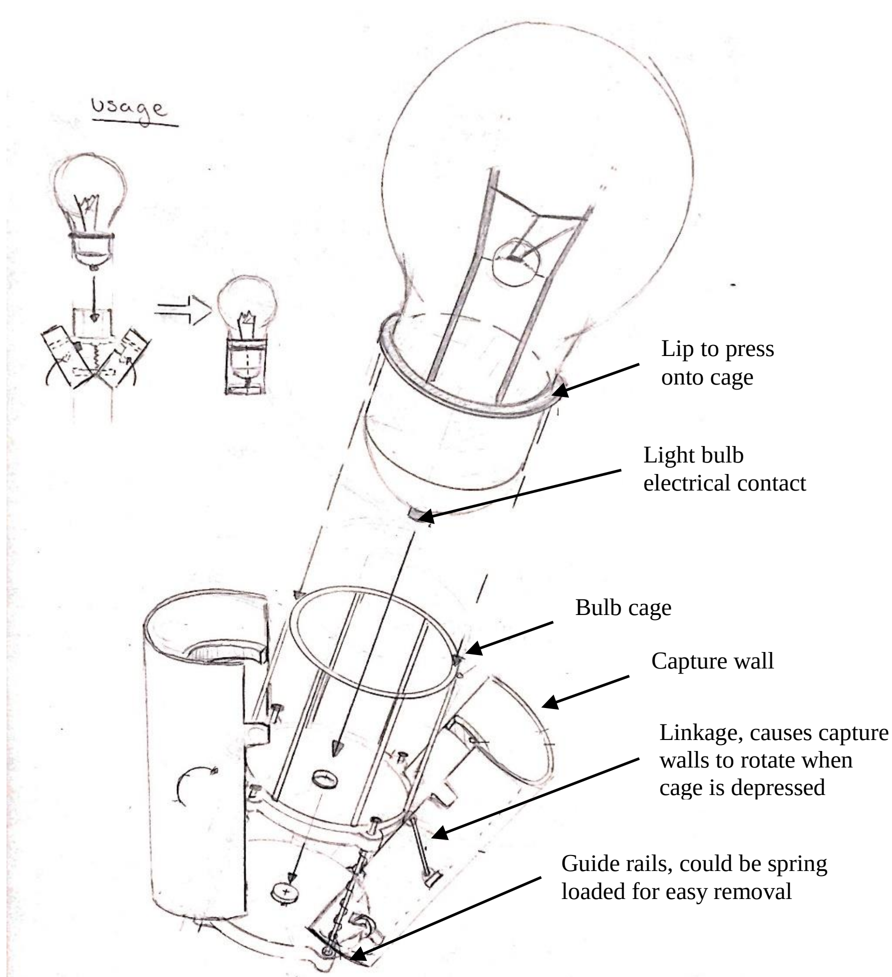


Figure 17. Representation of Modified Lightbulb.

Conclusions from Case Studies

These case studies provide a detailed depiction of the process of applying these design rules. In general, these rules are fairly simple to apply once the product's actionfunction diagram is created. The format of these design rules aids greatly in their application, as the rules directly interact with the product functions and user activities in the actionfunction diagram. Conversely, interpreting the changes suggested by the design rules takes some skill and consideration. Parametric changes can be easy to interpret, as it is a fairly simple task to visualize changes in product dimensions. Morphological and functional changes require more thought, as it is more difficult to decide which possible morphological or functional change would lead to the most inclusive possible design.

Another observation from these case studies is that some design rules are very trivial in application. These trivial cases are all related to parametric changes to architectural products, i.e. environments or products where the space around the product is an important consideration. In this case we are defining trivial cases as those where the proposed changes are very simple and very obviously lead to a more inclusive product. These trivial cases are identified as Cases 9, 31, and 33. Case 9 involves parametric changes to environments to allow easier entry and exit. Case 31 involves a parametric change to how a user maintains their body position when they position themselves while using a product. Case 33 involves a parametric change to how a user transfers themselves into or out of a product or environment. These trivial cases are omitted from the following experimental study.

Overall, each newly designed product seems more inclusive than the original typical product in each case. To gain more insight on the inclusivity of these newly designed products, and therefore gain a measure of the efficacy of the related design rules, we then performed an experimental survey study.

Experimental Approach and Study

In order to gain more statistically significant insight into the efficacy of these design rules, we have developed a survey study. This study polls potential users, and people with experience in inclusive design, on the modified products from the aforementioned case studies. The following sections provide the details of the conducted survey. It should be noted that this survey is not intended to show that these design rules lead to more inclusive products than in cases without design rules, as that research has already been conducted [3]. As a note, the previously discussed trivial cases – Case 9, 31, and 33 - are omitted due to their trivial nature.

Study Hypothesis

The purpose of this survey is to gauge the inclusivity of the newly designed products. From this gauge on redesign inclusivity, we seek to gain insight on the effectiveness of the design rules. Our hypothesis is that these design rules have a positive effect on product inclusivity, and lead to more inclusive products.

Pilot Study

We conducted a pilot study to gain preliminary insight on the effectiveness of these survey questions. Four graduate students, with experience in product design, were given the proposed survey questions.

There was a preliminary concern that participants would be unable to determine how the newly designed products functioned based on images alone. To determine if this would be an issue, the pilot study participants were asked to describe how well they understood how the newly designed products functioned from the provided descriptions and sketches. The pilot study participants reported that it was easy to determine how each redesigned product functioned from the provided descriptions and sketches. In order to gauge how well the participants of the survey understand how the newly redesigned products and environments function, we added question 1 to both of the Likert-type rubrics (Tables 6 and 7).

Survey Questions and Procedure

The survey participants were given eight or nine cases on products that were redesigned using the inclusive design rules. Each case described the original product being considered, as well as issues that users with certain disabilities may face when using it. Each case also described the design rule's suggested modifications, and provided a description and sketch of the newly redesigned product. For cases that are more trivial, such as rules describing that doors should be made wider, an image or sketch was not provided.

The survey follows the format of the Perceived Usefulness, Perceived Ease of Use survey developed by researchers at the University of Michigan [23]. This survey provides a proxy of the perceived usefulness of the newly designed products, which in turn reflects on their perceived inclusivity. For each case, the participants are given a set of Likert-type questions meant to gauge their opinion on the inclusivity of the newly redesigned product. These rubrics, shown in Table 8 and Table 9, ask the potential user to rate how beneficial they think the modified product will be in certain aspects. The full catalog of survey questions, as they appear in the study, are provided in Appendix E.

Table 8. Likert-type Questions for Cases with Provided Sketches

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how this product functions	◯	◯	◯	◯	◯
2. Overall I think this product would be easy to use.	◯	◯	◯	◯	◯
3. I can understand how this product addresses users with disabilities	◯	◯	◯	◯	◯
4. I think this product will increase disabled users' productivity.	◯	◯	◯	◯	◯
5. I think this product would make disabled users' jobs easier.	◯	◯	◯	◯	◯
6. Overall, I think this product would be useful for users with disabilities	◯	◯	◯	◯	◯
7. Overall, I think this product would be useful for users without disabilities	◯	◯	◯	◯	◯
Additional Comments/Feedback:					

Table 9. Likert-type Questions for Cases without Sketches

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how these changes would be implemented	◯	◯	◯	◯	◯
2. I can understand how these changes address users with disabilities.	◯	◯	◯	◯	◯
3. Overall, I think these changes would be useful for users with disabilities.	◯	◯	◯	◯	◯
4. Overall, I think these changes would be useful for users without disabilities.	◯	◯	◯	◯	◯
Additional Comments/Feedback:					

Survey Population

The participants in this study are meant to be people with some degree of experience in the fields of inclusive design or product design. The participants in this study include individuals with experience in developing inclusive products, and individuals who suffer from some degree of disability and have experience utilizing inclusive products. The potential users in this survey include users who have some level of disability, and who are likely to benefit from more inclusive products.

Over 320 individuals were contacted to participate in this study, as per IRB2016-0442D, from whom 68 valid responses were received. 6 of these responses were from city and university ADA coordinators, who oversee ADA compliance and provide an inclusive environment for their constituencies. 7 of these responses were from members of the Texas Governor’s Committee on People with Disabilities who are interested in technology and accessible products. 3 responses were received from Texas city accessibility and compliance specialists. 46 responses were received from graduate students in an advanced product design course, who have been studying methods of inclusive and universal design. 6 responses were received from individuals from the Adjustment to Disability group in REACH of Fort Worth, an organization that provides services for people with disabilities so that they may lead better and more independent lives.

Measures of Perceived Inclusivity

It is common practice in measuring less concrete concepts, such as inclusivity, to group several Likert-type items in order to better capture the concept being analyzed. In these less concrete cases, a single survey item is unlikely to fully describe the concept being analyzed. In our survey, we attempt to measure the perceived inclusivity of newly designed products through the seven aforementioned Likert-type questions. These questions individually measure some degree of usefulness, usability, or accessibility; and when certain questions are grouped, they can provide a more substantial measure of perceived product inclusivity. As a note, we are omitting Question 1 (from both rubrics, Table 8 and Table 9) from these groups, as it is asked solely to gauge if survey participants can understand the proposed design.

For the set of survey cases in which we provide sketches (rubric characterized in Table 8), we can combine questions 2, 3, 4, 5, 6, 7 to create a better measure of perceived inclusivity. Similarly, for the set of more trivial survey cases in which we do not provide sketches (rubric characterized in Table 9), we combine questions 2, 3, and 4. We utilized the Cronbach alpha measure to show that these questions are sufficiently intercorrelated, so that we may use the grouped items to measure our underlying concept – perceived inclusivity.

To analyze our data and thus calculate Cronbach's alpha, we utilize an ANOVA Two-Factor analysis. Qualitatively, alpha values of 0.7 to 0.8 are regarded as a satisfactory level of intercorrelation [24]. The following tables depict the alpha values from each case, and it should be noted that most values exceed the 0.7 benchmark for correlation. Because an overwhelming majority of alpha values exceed 0.7, we say that the questions in our cases are sufficiently intercorrelated, and thus we can justify grouping the survey questions as we described above. In the Data Analysis portion of our paper, we now combine the questions as previously mentioned in order to create a numerical measure of perceived inclusivity. This numerical measure is found by taking the median value of all the questions (excluding Question 1 on comprehension).

Table 10. Alpha Values for Cases with Sketches (Combining Questions 2,3,4,5,6,7 from Table 7)

Case	Alpha	Case	Alpha
1.1	0.86	**11.2**	0.82
1.2	0.83	**12**	0.85
2	0.83	**13**	0.84
3	0.96	**22**	0.88
4	0.93	**25**	0.94
6	0.83	**26**	0.92
7	0.82	**28**	0.89
8	0.85	**32**	0.83
11.1	0.80		

Table 11. Alpha Values for Cases without Sketches (Combining Questions 2,3,4 from Table 8)

Case	Alpha	Case	Alpha
5	0.80	**20**	0.76
10	0.87	**21**	0.81
14	0.66	**23**	0.90
15	0.79	**24**	0.79
16	0.40	**27**	0.94
17	0.81	**29**	0.90
18	0.75	**30**	0.76
19	0.89	**34**	0.60

Data Analysis Methods

This study uses Likert-type, ordinal ranking data; and because these products were redesigned using inclusive design rules, we assume that data does not follow a normal distribution. As such, we assume that nonparametric methods are required to analyze this data. Means are of limited value if the data does not follow a normal distribution. Because of this, we characterize the central tendency of our data using the median of results [25]. In our data analysis, we assign values to each of the Likert-type responses as such: 5 - Strongly Agree, 4 – Agree, 3 – Neither Agree nor Disagree (Neutral), 2 – Disagree, and 1 – Strongly Disagree.

Our data is not normally distributed and asymmetric, so we use a nonparametric 1-sample sign test to determine if we can reject the null hypothesis. We are comparing our data to a hypothesized median of 3 (or Neutral). We interpret a survey median greater than 3 as the population viewing our redesigned products as more inclusive than their typical counterparts. The full data sets, along with visualizations for the responses, can be found in Appendix F.

Table 12. Perceived Inclusivity of Cases with Sketches

CASE	MEDIAN PERCEIVED INCLUSIVITY	CASE	MEDIAN PERCEIVED INCLUSIVITY
1.1	3	**11.2**	4
1.2	4	**12**	4
2	4	**13**	4
3	4	**22**	4
4	4	**25**	4
6	4	**26**	4
7	4	**28**	4
8	4	**32**	4
11.1	4		

Table 13. Perceived Inclusivity of Cases without Sketches

CASE	MEDIAN PERCEIVED INCLUSIVITY	CASE	MEDIAN PERCEIVED INCLUSIVITY
5	5	**20**	5
10	5	**21**	4
14	5	**23**	4
15	5	**24**	4.5
16	5	**27**	4
17	4	**29**	5
18	4	**30**	4
19	5	**34**	5

Survey Results and Discussion

As shown in Table 12 and Table 13, a majority of cases received median perceived inclusivity values of 4 or higher, indicating that survey participants felt the newly designed products and environments were inclusive. Case 1.1 is the sole outlier with a median perceived inclusivity value of 3. One possible reason for this deviation is that two survey participants reported that they did not understand how the bed sheet gripping arm of Case 1.1 functioned, then proceeded to answer each question with Disagree.

The results of this survey could be used to support Sangelkar's studies on inclusive design rules. Sangelkar's results showed that the actionfunction representation scheme's, and inclusive design rules', efficacy was problem dependent; and that they were effective in designing architectural products or environments. [3]. A majority of these cases; excluding cases 9, 10, 21, and 30; are products, and the survey results indicate that these design rules are also useful in developing more inclusive consumer products.

Experimental Survey Summary and Conclusions

This research seeks to aid in the creation of fundamental knowledge and methods for engineering design that would enable engineers to better practice inclusive design. This work supplements previous research in the field of inclusive design rules, in the form of providing evidence of their effectiveness in the field of consumer products.

There are several avenues for future work in this research. The experimental survey conducted in this research received less responses than initially planned. Reaching a larger survey population could lead to more significant insight on the results of applying these design rules. On another note, the case studies in this work apply and analyze these design rules on a rule-by-rule basis, so each typical case product has only been modified by a single rule. While this is useful for analyzing how each design rule works, it would be beneficial to analyze the application of multiple design rules on each product. It is possible that the changes suggested by multiple rules may interact in unexpected ways. Similarly, the products that were analyzed in this work are fairly simple; and it may be beneficial to analyze the application and effects of these design rules in increasingly complex products and systems. One far-reaching area of future work could be the development of a method to identify which design rules to apply to a certain product. This could be through optimization methods that analyze the effectiveness of each design rule and the costs incurred by their suggested modifications.

The results of this research provide insight on the application and interpretation of inclusive design rules in the actionfunction diagram representation scheme. The case studies of this work explain the process of modifying a product using these design rules, and show that the rules can lead to redesigned products. The experimental survey results show that these design rules can lead to inclusive products.

Validation Study

In order for these rules and design methods to be useful, they must be usable and consistently produce inclusive products. Prior research suggests that these design rules, and the related actionfunction diagram scheme, are problem dependent in their effectiveness [3]. In order to further supplement this research and provide evidence on the efficacy of these design rules, we have performed a validation study.

Participants were given an hour lecture on inclusive and universal design, actionfunction diagrams, and inclusive design rules in order to raise awareness of inclusive design methods. Participants were then given the actionfunction models of typical products, and tasked with applying these inclusive design rules. After applying the design rules to these products, participants were given a feedback form, based on the System Usability Survey [26], which aimed to gauge the usability of actionfunction diagrams and inclusive design rules.

Validation Study Approach

This section details the procedures involved in the validation study. The survey population, study format, and study process are all described below.

Validation Study Participants

This lecture and study occur in MEEN 601 at Texas A&M University during the Fall 2016 semester. MEEN 601 is the Advanced Product Design course for graduate students at Texas A&M, and focuses on teaching systematic design methodologies and design process models. The survey population consisted of 28 mechanical engineering graduate students. These survey participants received prior training in functional models and activity diagrams as part of MEEN 601. This study was conducted as an in-class exercise, for which they received assignment credit. Survey non-participants were given the chance to receive the same credit through an alternate assignment.

Validation Study Process

The study participants are randomly divided into three groups, referred to as Groups 1, 2, and 3. The problems are taken from the aforementioned case studies, and are split evenly between these three groups. The study takes place over two consecutive class days. The first day began with a lecture on inclusive design. This lecture presents an introduction on inclusive and universal design, the actionfunction diagram method, and inclusive design rules. Participants are taught the process of creating an actionfunction diagram and applying inclusive design rules. Participants are also taught how to interpret the changes suggested by these design rules.

The participants are given the survey questions on the second day. During the second lecture time, the participants are given a brief refresher lecture on inclusive design and inclusive design rules. After the refresher, participants are given the studies, which task them with applying inclusive design rules to the typical products from the previous case studies. The total validation study process is 75 minutes including the time allotted for the refresher lecture and consent process.

Validation Study Format

Each participant is given five cases. These cases provide a description of the typical product in question, and several difficulties that disabled or otherwise limited users might face when using the product. The given typical products are the same products that were looked at in the Case Studies chapter of this work, as the redesigned products in the Case Studies can provide a baseline from which to gauge participant responses. For each case and typical product, the participants are tasked with identifying any relevant design rules from the provided list, and applying the chosen rules to the given product's actionfunction diagram. After applying any relevant design rules, the participants are then asked to describe how the suggested changes can be interpreted, and to provide a sketch or detailed description of how the new product works. These survey questions and their accompanying descriptions can be found in Appendix G.

After completing the given questions, the survey participants are then given an exit questionnaire that is meant to assess the usability of the inclusive design methods in the validation study. Participants are asked to rate their opinions on various statements related to the method's usefulness and usability. Here, method refers to the use of actionfunction diagrams to model user-product interaction and the use of inclusive design rules to aid in designing more accessible products. This questionnaire is shown below, and is based off of the System Usability Scale [26].

Table 14. Validation Study Feedback Questionnaire

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I think that I would like to use actionfunction diagrams for inclusive design	○	○	○	○	○
I found actionfunction diagrams unnecessarily complex.	○	○	○	○	○
I thought the actionfunction diagram method was easy to use	○	○	○	○	○
I would imagine that most engineers could learn to use actionfunction diagrams quickly	○	○	○	○	○
I think that I would like to use these inclusive design rules in the design process.	○	○	○	○	○
I found the inclusive design rules unnecessarily complex.	○	○	○	○	○
I thought the inclusive design rules were easy to apply.	○	○	○	○	○
I was able to identify an applicable inclusive design rule in these problems.	○	○	○	○	○
I would imagine that most engineers could learn to use these inclusive design rules quickly.	○	○	○	○	○
I needed to learn a lot of things before I could get going with these methods.	○	○	○	○	○
With more practice I think I could become very proficient in using these methods.	○	○	○	○	○
Please provide any additional feedback here:					

Study Observations and Results

The participants' redesigned products will be analyzed and graded on their inclusivity, in order to gain evidence that these design rules can lead to more inclusive products. All participants' identifying information is stripped before the inclusivity rating process. The inclusivity graders are three graduate mechanical engineering students from Texas A&M University, and specialize in engineering design research. The main grader rates all of the new inclusive designs, and the two remaining graders analyze subsets of the data to ensure scale reliability.

Inclusivity Scale Rating

In her research, Sangelkar created a 4-point scale to rate the inclusivity of newly designed products. Products are scored between 0, indicating low inclusivity, and 3, indicating high inclusivity. Sangelkar's rating system assigns scores based on whether a product addresses disability, works for disability, and is good for people without disability [3]. The flowchart below provides the decision making process from which the graders decide inclusivity ratings. A product scoring a 0 rating for inclusivity would be one that only modifies the inner workings of a product, or does not address any limitations disabled users may have (e.g. improving product aesthetics without providing any additional benefit). A product scoring a 1 would be a product that seems to address disabled users' limitations, but that does not actually alleviate those limitations. Products scoring a 2 or higher are inclusive products; an inclusivity rating of 2 indicates a product that is useful for disabled users but not people without disability (e.g. chairlifts on cars), whereas an inclusivity rating of 3 indicates products that are useful for all people (e.g. automatic motion sensing doors). Table 15 further explains the meaning of inclusivity ratings [3].

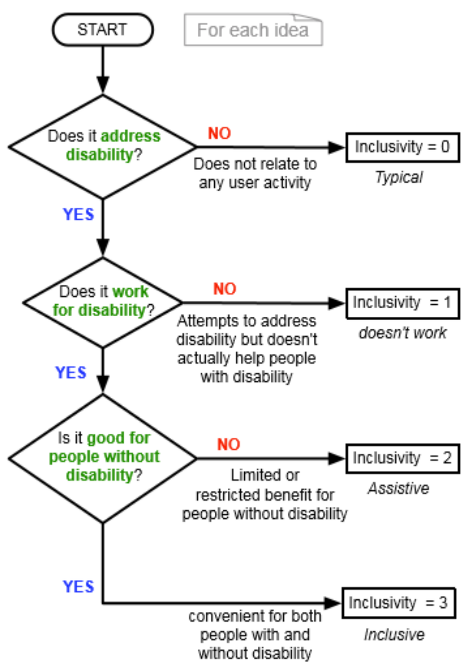


Figure 18. Inclusivity Rating Scale [3]

Table 15. Meaning of Inclusivity Ratings (adapted from [3])

Inclusivity	Meaning	Examples
I = 0	Ideas that do not relate to any user activity	1. Anything related to aesthetics
		2. Improved cutter designs
		3. Any electrical energy related ideas
I = 1	Ideas related to some user activity but do not work for disability	1. Soundproofing
		2. Ramp for refrigerator
		3. Use knife and cutting board
I = 2	Ideas that address disability but not good for people without disability	1. Provide a magnifying glass
		2. Complicated assistive devices
		3. Shorter and wider refrigerator
I = 3	Ideas that are good for both people with and without disability	1. Automatic garage door opener
		2. Motion sensing automatic faucet
		3. Retractable electric cord

Inter-Rater Agreement and Reliability

To ensure inter-rater reliability in grading scores, we analyze the agreement between raters using Cohen's kappa. Table 16 below reports Cohen's kappa values between the main rater and each additional rater. The Cohen's kappa values show moderate agreement between the raters. From this we determine that the scored inclusivity ratings are reasonably reliable.

Table 16. Cronbach's Alpha for Inter-Rater Agreement

Grading Pair	Cohen's Kappa
Main Grader – Add. Grader 1	0.459
Main Grader – Add. Grader 2	0.613

Validation Study Results

The validation study results are first analyzed on a per-group basis. In general, participants produced more inclusive results than did not. As a note, we omitted responses that did not utilize the inclusive design rules. Figure 19 shows the number and inclusivity ratings of concepts for each group. The inclusive design rules and actionfunction diagrams lead to more inclusive product design concepts than not.

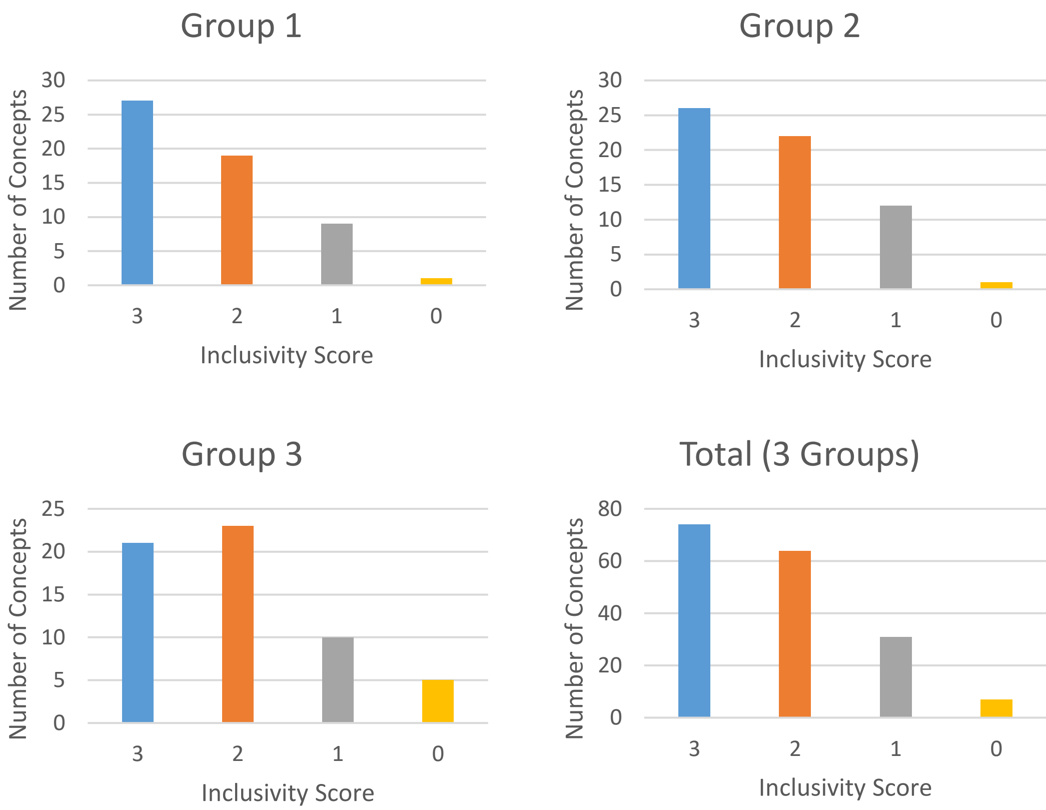


Figure 19. Rated Results per Group

Overall, participants produced inclusive products in the validation study. Furthermore, on a case by case basis, participants produced more inclusive designs than not. Figure 20, **Error! Reference source not found.**, and **Error! Reference source not found.** detail the results for each individual case. The only exception to the increased inclusivity is Case 12; however, all other cases show that participants can design inclusive products when using these inclusive design rules.

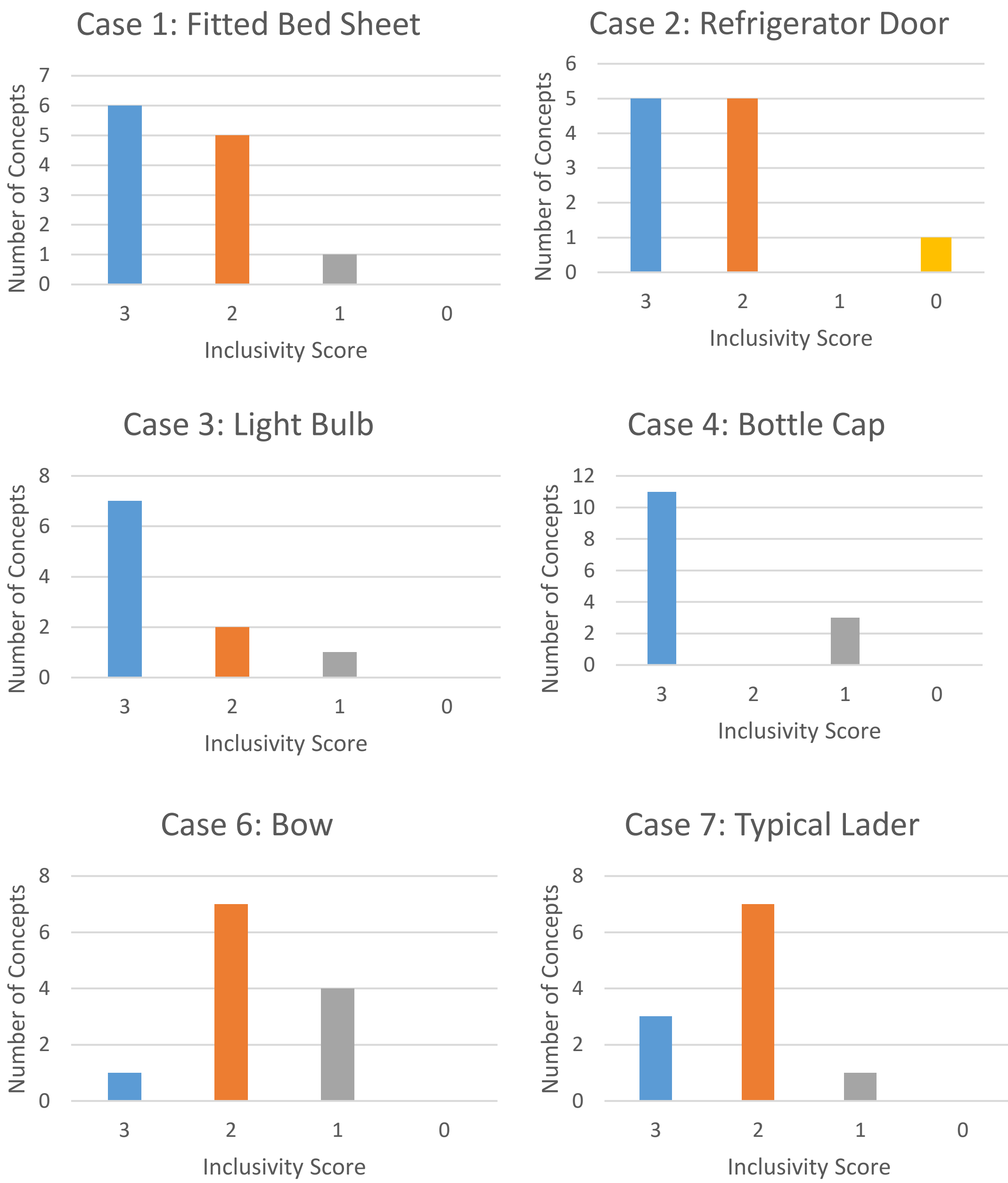


Figure 20. Case by Case Results

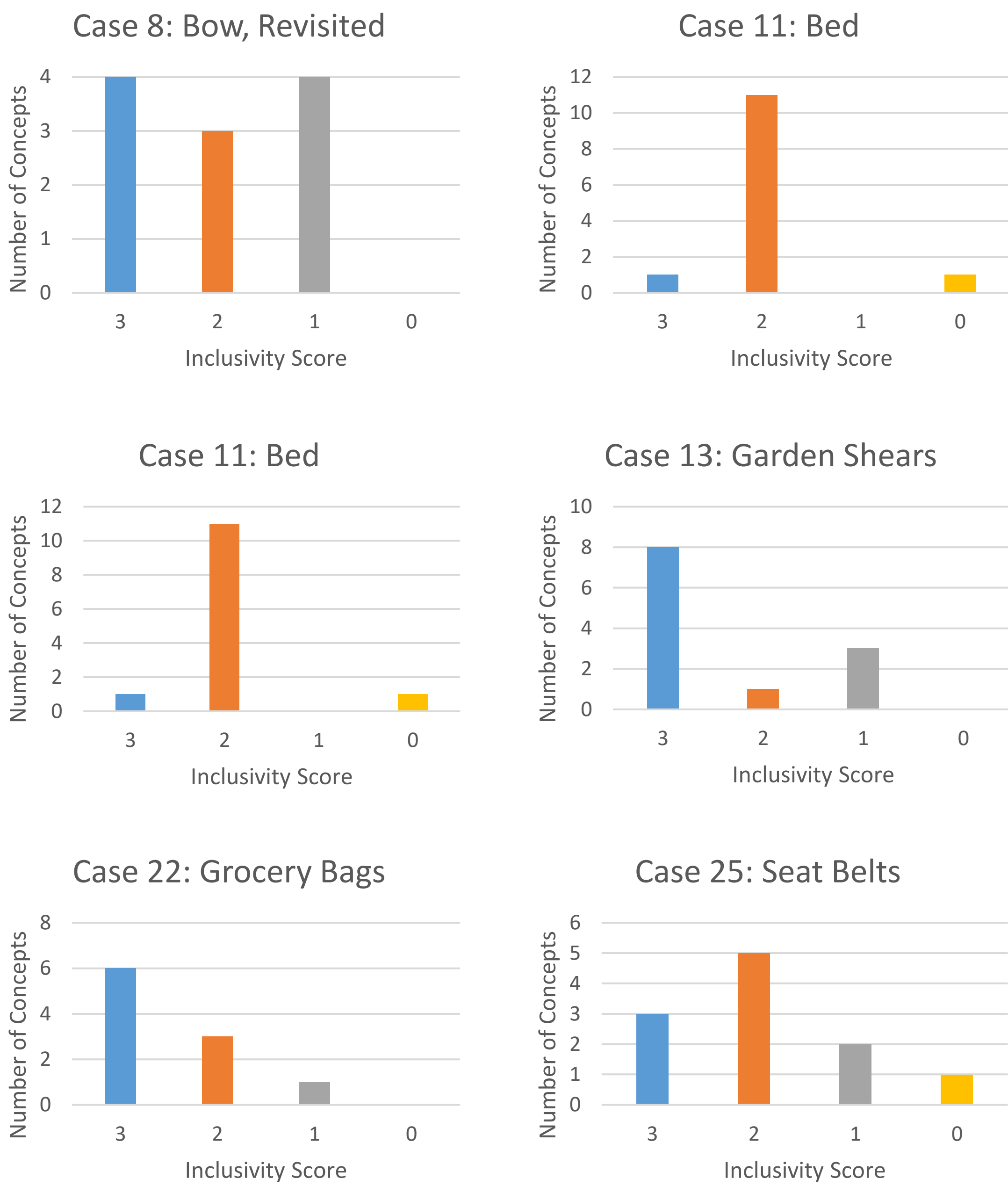
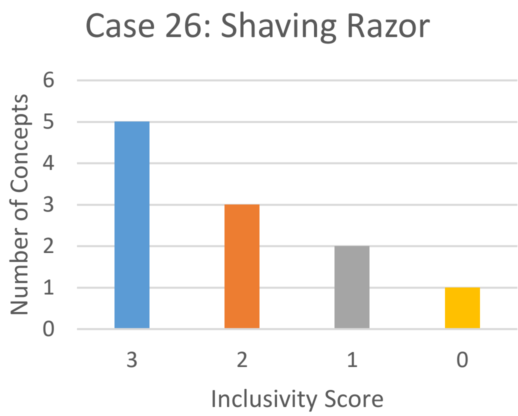
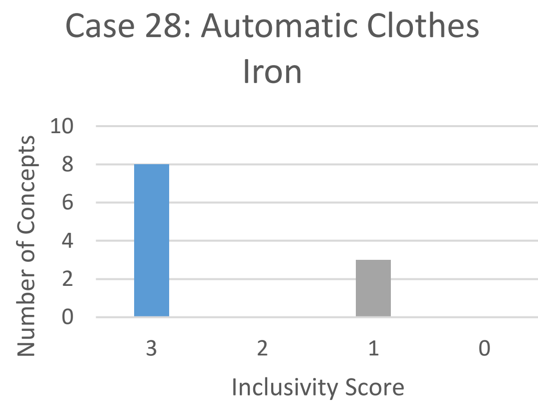


Figure 20. Case by Case Results (cont.)





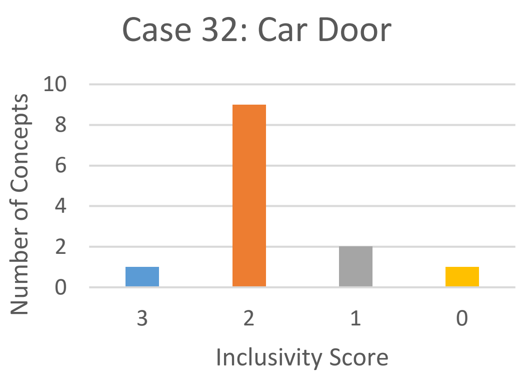


Figure 20. Case by Case Results (cont.)

Validation Study Feedback

Study participants provided feedback on the actionfunction diagram method and inclusive design rules used in the study exercise. This feedback was provided in the form of an exit questionnaire that is modeled after the questions from the System Usability Scale (SUS) [26]. Previously shown in Table 14, this questionnaire asks participants several Likert-type questions that gauge the usability of actionfunction diagrams and the inclusive design rules based on participants' experience in the validation study. Table 17 depicts the number and percentage of participant responses to the feedback questionnaire.

Table 17. Validation Study Feedback Responses

Grouping	Feedback Questions	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Actionfunction Diagrams	I think that I would like to use actionfunction diagrams for inclusive design	**7 (25%)**	**17 (61%)**	**3 (11%)**	**1 (4%)**	**0**
	I did not find actionfunction diagrams unnecessarily complex.	**0**	**13 (46%)**	**9 (32%)**	**4 (14%)**	**2 (7%)**
	I thought the actionfunction diagram method was easy to use	**4 (14%)**	**8 (29%)**	**13 (46%)**	**4 (11%)**	**0**
	I would imagine that most engineers could learn to use actionfunction diagrams quickly	**5 (18%)**	**17 (61%)**	**5 (18%)**	**1 (4%)**	**0**
Inclusive Design Rules	I think that I would like to use these inclusive design rules in the design process.	**5 (18%)**	**15 (54%)**	**6 (21%)**	**2 (7%)**	**0**
	I did not find the inclusive design rules unnecessarily complex.	**3 (11%)**	**12 (43%)**	**9 (32%)**	**4 (14%)**	**0**
	I thought the inclusive design rules were easy to apply.	**2 (7%)**	**15 (54%)**	**7 (25%)**	**4 (14%)**	**0**
	I was able to identify an applicable inclusive design rule in these problems.	**2 (7%)**	**15 (54%)**	**11 (39%)**	**0**	**0**
	I would imagine that most engineers could learn to use these inclusive design rules quickly.	**7 (25%)**	**14 (50%)**	**6 (21%)**	**1 (4%)**	**0**
Overall	I did not need to learn a lot of things before I could get going with these methods.	**1 (4%)**	**7 (25%)**	**12 (43%)**	**5 (18%)**	**3 (11%)**
	With more practice I think I could become very proficient in using these methods.	**10 (36%)**	**16 (57%)**	**2 (7%)**	**0**	**0**

Participants responded positively overall. Eighty-six percent of participants reported that they would like to use the actionfunction diagram method to practice inclusive design. Similarly, seventy-one percent of participants reported that they would like to use the inclusive design rules in the design process. The only exceptions to the overall positive results are in the complexity and ease of use of actionfunction diagrams. When asked if they thought actionfunction diagrams were easy to use, forty-three percent of participants responded "Strongly Agree" or "Agree", while forty-six percent responded neutrally. While a plurality of participants (forty-six percent) did not find actionfunction diagrams unnecessarily complex, a majority responded neutrally or negatively.

Participants received a detailed lecture on actionfunction diagrams and inclusive design rules; however, they did not have any assignments involving inclusive design prior to this validation study. It is possible that the methods involved in actionfunction diagrams have a steep "learning curve", which would account for the aforementioned responses. A majority of participants did report that they felt they could become very proficient in actionfunction diagrams and inclusive design rules.

Coupling participants' feedback with the validation study results provides some interesting insight. Concepts generated by participants who responded positively regarding actionfunction diagrams (combining the results of the grouped questions in Table 17) had a higher average inclusivity score than concepts generated by those who responded negatively (p-value 0.02) (Figure 21). Participants who responded positively regarding actionfunction diagrams created products with a higher average inclusivity score than participants who responded negatively (p-value 0.13) (Figure 22).

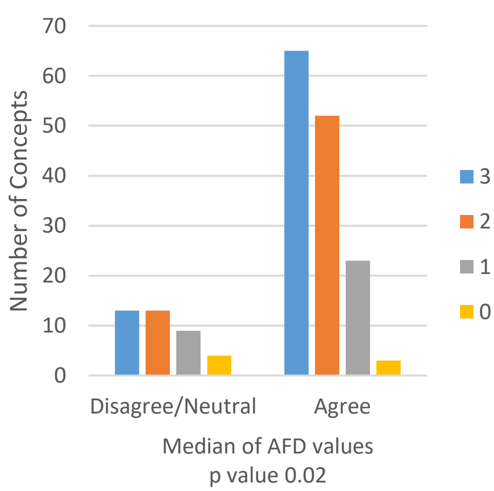
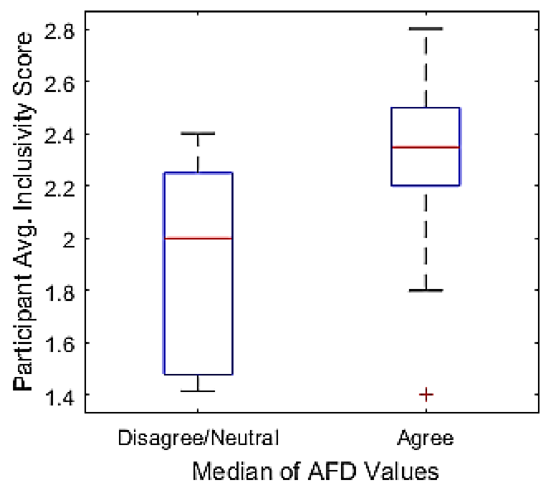


Figure 21. Comparing Understanding of Actionfunction Diagrams (AFD) to Concept Inclusivity



p value 0.13

Figure 22. Comparing Understanding of Actionfunction Diagrams (AFD) to Participant Average Inclusivity

Concepts generated by participants who responded positively regarding inclusive design rules had a higher average inclusivity score than concepts generated by those who responded negatively (p-value 0.03) (Figure 23). Similarly, participants who responded positively regarding inclusive design rules created products with overall higher average inclusivity values (p-value 0.05) (Figure 24).

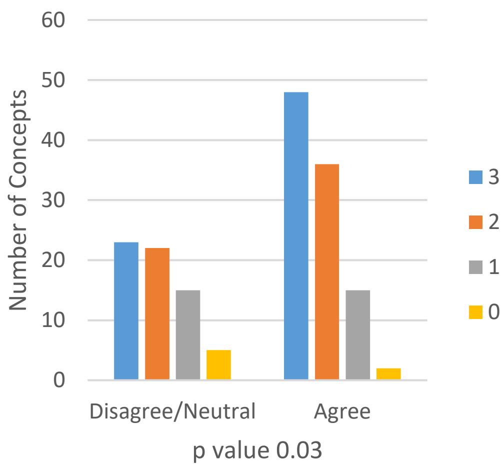
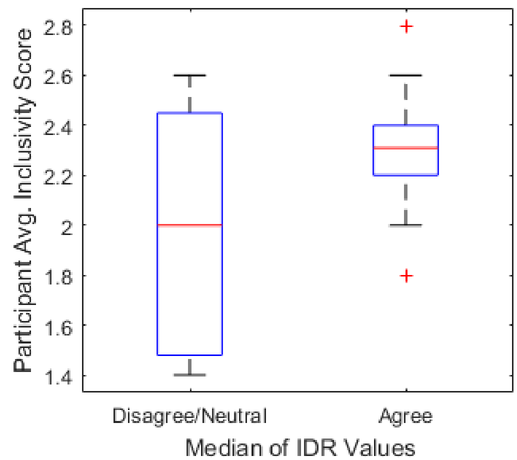


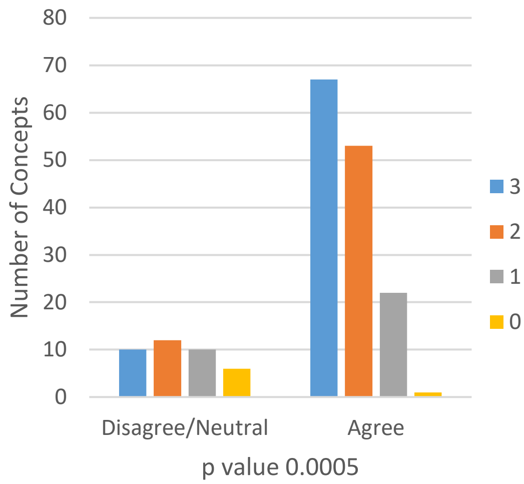
Figure 23. Comparing Understanding of Inclusive Design Rules (IDRs) to Concept Inclusivity



p value 0.05

Figure 24. Comparing Understanding of Inclusive Design Rules (IDR) to Participant Average Inclusivity

Concept inclusivity and participants' average inclusivity values both increased with increasing participant feedback values. An even more significant observation is that participants who responded positively overall to the feedback questionnaire designed products with substantially higher average inclusivity values (Figure 25). Likewise, concepts generated by participants who responded positively overall on the questionnaire had a higher average inclusivity score than concepts generated by those who responded negatively (p-value 0.0005) (Figure 26).



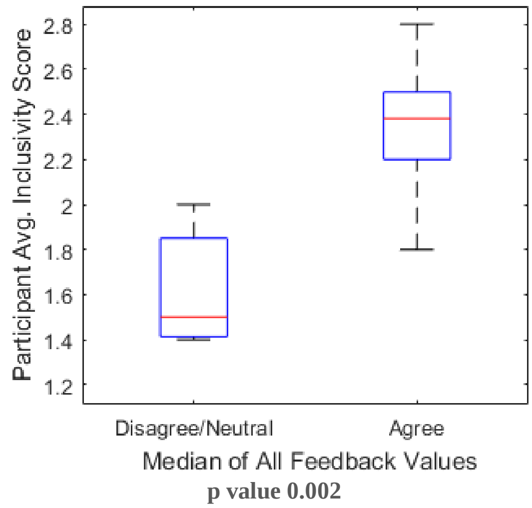


Figure 25. Comparing Understanding of Methods to Concept Inclusivity

Figure 26. Comparing Understanding of Methods to Participant Average Inclusivity

Validation Study Summary and Conclusions

In this validation study, graduate student participants were tasked with redesigning certain products using inclusive design rules. Participants were first given a lecture on inclusive and universal design, actionfunction diagrams, and inclusive design rules. Each participant was tasked with applying the inclusive design rules to a typical product in five cases. Using these design rules, participants designed more inclusive products than not. Additionally, participants' self-reported feedback indicates that, overall, participants find actionfunction diagrams and inclusive design rules (referred to collectively as "methods") useful and usable. The study results show significant correlation between participant's feelings on the methods' usability and the average inclusivity of concepts participants generated. These results help show that actionfunction diagrams and inclusive design rules are useful in developing inclusive consumer products.

4. CONCLUSIONS

Summary

We analyzed inclusive design rules; first by observation, then by an in-depth case study. These case studies analyzed how inclusive design rules are applied to consumer products, and what modifications can result. We then studied potential users' and experienced designers' opinions regarding the inclusivity of these products in order to gain insight on the effectiveness of the design rules. We further analyzed these design rules in a second validation study that tasked participants with redesigning typical products with the given design rules. From this, we gained insight on how the participants apply the design rules, and what effects they have on product inclusivity.

Overall, these design rules seem to lead to more inclusive consumer products. From observation alone, the redesigned products in the case study appear more inclusive than the typical products from which they came. Survey feedback shows that potential users and experienced designers believed the redesigned products to be inclusive. In the validation study, designers developed significantly more concepts that were inclusive than were not. Additionally, designers who responded positively regarding the actionfunction diagrams and inclusive design rules designed products with significantly higher average inclusivity values. Validation study feedback shows that designers found the actionfunction diagram and inclusive design rules useful and usable. Designers reported that they felt inclusive design rules were easy to apply, as they directly interacted with the actionfunction diagram format. Designers felt that these rules were helpful in designing inclusive products, as they provided clear direction for the design process. Typically, engineers design with an abstracted functional format; design rules that directly interact with this abstracted format and provide clear direction are a powerful resource for inclusive design.

Limitations

There are four primary assumptions made throughout this work, from which we see four limitations. The first of which is that every consumer product is amenable to being modified by these inclusive design rules. While the inclusive design rules cover a very wide range of user activities and product functions, it is reasonable to say that there exist products that do not have any user activity-product function combinations from the given inclusive design rules set. If a product's user activity-product function combinations do not match any of those in the inclusive design rule set, then that product cannot be modified by the inclusive design rules. One possible solution to this limitation could be to expand the design rule set by analyzing a larger set of inclusive product pairs.

Particularly, in the context of optimization, a second limitation stems from the lack of weighting for the design rules. It is reasonable to assume that not all modifications are equally inclusive. Developing situation-dependent weighting systems for these design rules could help designers determine if certain rules may be more effective than others in certain situations. For instance, if considering products for the profoundly disabled, weighting rules that suggest functional or morphological changes more heavily would provide for a more informed, systematic approach.

A third limitation arises due to the fact that we applied a single rule to each product in the case studies. Our focus was the study of rule effectiveness. We singled out one rule to apply in each case in order to ensure the effects of each rule were being properly studied, and to avoid biasing those results with compounding effects from applying multiple rules.

The last major assumption in this research is that, in both the experimental and validation studies, the newly modified products are only conceptual sketches. While participants report that they understood how these products worked, physical embodiments of the products would provide a much more direct evaluation of usability and inclusivity.

Future Work

There are several avenues for future work in this research. As mentioned previously, developing a of weighting system for the design rules would be helpful in determining if certain rules are more useful in different situations. This could lead into developing an optimization system for applying these design rules. It would be useful to factor in how expensive (time-wise or monetary-wise) the suggested modifications are, and how many more users would be included as a result of the modifications. This optimization system could weigh the inclusivity of the design rule's suggested modification, the cost of applying said modification, and numerous other factors. This system could utilize a weighted decision matrix to determine which changes to apply, and determine to what extent those changes would increase a product's inclusivity.

Another avenue for future work could be applying these multiple inclusive design rules to products or systems. In the case studies and experimental study, only a single rule was applied to each product. These rules may have an additive or multiplicative effect that could be analyzed and exploited. A systematic study of how design rules are interrelated, and how their effects can be compounded, could further the field of inclusive design rules.

One very key avenue of future research involves building physical embodiments and prototypes of products that have been redesigned using these inclusive design rules. Allowing users to physically interact with redesigned products would lead to more concrete and useful information on product functionality and usability. Physical embodiments of redesigned products would also allow for a proper SUS study to be conducted which would provide a standardized measure of the redesigned products' usability, and thus inclusivity. Feedback from physical testing would be used in conjunction with this work in order to strengthen the validity of this inclusive design framework.

Closing Statement

The main contribution of this work is providing validation for the effectiveness of inclusive design rules in a product design context. An additional goal of this work was to provide a resource detailing the processes involved in applying inclusive design rules to typical products, and how to interpret the modifications suggested by these inclusive design rules. Given the context of this work, a broader contribution is the combination of concrete data (human capability design guidelines) with abstract data (inclusive design rules and actionfunction diagrams) to develop a more effective method for designing inclusive products. Functional modeling techniques, such as the actionfunction diagram, can be challenging to properly use, as the abstracted representation scheme may be too generalized and difficult for some to understand. Augmenting this representation scheme with contextual information from human capability design guidelines allows it to be more effective in designing inclusive products. In this work, we combine acontextual information (from actionfunction-inspired inclusive design rules) with highly contextual data (from human capability guidelines) to develop our human capability-sensitive design rules that are shown to be useful and usable in inclusive design.

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APPENDIX A: DESIGN GUIDELINE TRANSLATION

- Visual Design Guidelines
  - (**V-1**): "Attempt to make text as large as possible within the constraints of the design, and maximize the contrast between foreground text and the background",
  - **AND** (**V-2**): "Where possible use sans-serif fonts (such as Arial) at larger text sizes with plain instead of patterned backgrounds to increase clarity",
  - **AND** (**V-3**): "Avoid the use of decorative and cursive font styles (for example, fonts that mimic handwriting) in favor of clearer, more legible, sans-serif typefaces",
    - These guidelines involve a product's 'Indicate Status' function, as the text is responsible for conveying information to the reader. The relevant ICF user activity is 'Communication - Written'. Adjusting the font size and style entails a parametric change. The resulting design rule is (Indicate Status, Communication-written) → (Parametric)
  - (**V-4**): "Attempt to make graphical symbols as large and clear as possible within the constraints of the design",
  - **AND** (**V-5**): "Attempt maximum contrast between product parts (such as buttons, keys and other controls) against the product body within the constraints of the color palette chosen for a design project",
  - **AND** (**V-6**): "Keep the different forms of color blindness in mind when choosing the color palette for a design project. If red and green are to be used together, try to provide an alternative clue (such as a text description) as to what the lights mean."
    - These guidelines involve a product's 'Indicate Status' function, as graphics and controls are responsible for conveying information to the reader. The relevant ICF user activity is 'Communication - Nonverbal'. Adjusting symbol and control parameters, such as size or color, entails a parametric change. The resulting design rule is (Indicate Status, Communication-nonverbal) → (Parametric)
  - (**V-7**): Attempt to avoid shiny and highly reflective surfaces that increase the likelihood of glare problems, using materials with matte finishes where possible

- **AND** (**V-8**): “Reduce glare by positioning light sources away from the user's line of sight and by using shielding or diffusers on light sources”,
- **AND** (**V-9**): “Consider providing adjustable light sources (such as lamps) to allow different users to set the lighting environment to their needs”,
- **AND** (**V-10**): “Reduce glare and angle of view problems by providing displays and screens that can easily be repositioned”.
  - These guidelines also involve a product’s ‘Indicate Status’ function, as screens and displays are the most likely to be affected by glare. The relevant ICF user activity are ‘Seeing Functions”. Adjusting surface materials, creating adjustable screens and lights, and utilizing shields or diffusers are all morphological changes. The resulting design rule is (Indicate Status, Seeing Functions) → (Morphological, Seeing Functions).

- Hearing Design Guidelines
  - (**H-1**): “Make volume levels adjustable if possible and try to ensure that frequencies of sound are in the range 800 to 1000 Hz”,
  - **AND** (**H-5**): “Attempt to ensure that when sounds of high pitch are used, they are of a long duration to maximize detection”.
    - These guidelines involve the ‘Export Signal’ function. The relevant ICF user activity is ‘Hearing Functions’. Adjusting volume and frequency levels and regulating pitch length involves a parametric change. The resulting design rule is (Export Signal, Hearing Functions) → (Parametric). These guidelines also can lead to the rule of (Adjust Signal, Hearing Functions) → (Functional), as they suggest that, in order to make products more inclusive, there needs to be some functionality related to adjusting the volume.
  - (**H-2**): “Avoid synthesized speech in favor of natural speech (recorded) if possible, and use lower pitched voices in preference to higher pitched voices”.
    - This guideline involves the ‘Export Signal’ function. The relevant ICF user activity is ‘Hearing Functions’. Using a different method for providing speech entails a morphological change, but retains the user activity of ‘Hearing’ in

the inclusive design. The resulting design rule is (Export Signal, Hearing Functions) → (Morphological, Hearing Functions)

- (**H-3**): "Attempt to provide alternative feedback (such as visual or tactile) for people with very low hearing ability and facilitate connections with auditory aids".
  - This guideline involves the 'Export Signal' function. The relevant ICF user activity is 'Hearing Functions'. Using a different method for providing information entails a morphological change to an alternative perceptual function in terms of user activity. The resulting design rule is (Export Signal, Hearing Functions) → (Morphological, Alternative Perceptual Functions)
- (**H-4**): "Design environments and spaces to minimize background noises, sound reflection, and reverberation as much as possible to ensure clarity of sound transmission".
  - This guideline is difficult to accurately translate, as the change is to an environment, not a product's function. Background noise would affect the 'Export Signal' functions of products in the environment, and would involve the hearing functions of the involved users. Designing for background noise suppression would entail morphological changes, while retaining the user activity of 'Hearing'. Therefore, this guideline is already captured in the (Export Signal, Hearing Functions) → (Morphological, Hearing Functions) rule from guideline (**H-2**).

- Communication Design Guidelines
  - (**C-1**): "Ensure the areas that the user can interact with, and the correct way to interact with them, are obvious from the overall form of the device".
    - This guideline is difficult to fully classify, as it involves all the possible functions a user can interface with on a specified product, so for the purpose of translating this rule, we have selected 'Interface with Product' as the relevant function. This general choice of product function should cover any function that requires the user to directly interact with the product. The relevant user activity is 'Perceptual Functions', as this guideline involves using various forms of feedback to perceive the correct way to interact with

a product. Ensuring that all controls and interfaces are laid out intuitively would entail a morphological change while retaining the user activity of 'Perceptual Functions'. The resulting design rule is (Interface with Product, Perceptual Functions) → (Morphological, Perceptual Functions)

- (**C-2**): "Ensure that an uninitiated user can form a correct mental model of how the controls will affect the product and provide positive feedback so that the user can ascertain when their actions have been successful",
- **AND** (**C-3**): "Ensure that the current state or mode of the device is obvious and avoid unnecessarily high demands on user capabilities during product interaction",
- **AND** (**C-4**): "Provide helpful assistance in the event that the user has performed an incorrect action, detailing why their action was unsuccessful and what options are available",
- **AND** (**C-5**): "Minimize the adverse consequences when errors or mistakes do occur and ensure all actions are reversible".
  - The forming a correct model portion of (**C-2)** has already been satisfied in (**C-1**). Providing positive feedback (**C-2**), product status information (**C-3**), and troubleshooting assistance (**C-4 and C-5**), would all involve a product's 'Indicate Status' or 'Indicate Feedback' functions and would involve the user activity of 'Perceptual Functions'. These guidelines involve a functional change of adding a positive feedback function, a product status update, or troubleshooting assistance. Thus, these guidelines all translate to: (Indicate Status, Perceptual Functions) → (Functional, Perceptual Functions)
- (**C-6**): "Provide the potential for information to be transferred by different modes, such as textual, verbal, pictorial, tactile, lights and sounds".
  - This guideline involves a product's 'Indicate Status' function and the user activity of 'Perceptual Functions', as it involves how a product conveys information. Ensuring that the product conveys information through alternative means entails a morphological change while retaining the user activity of 'Perceptual Functions'. The resulting design rule is (Indicate Status, Perceptual Functions) → (Morphological, Perceptual Functions)

- Locomotion Design Guidelines
    - (**L-1**): “Attempt to provide adequate space for access and egress when designing doorways, entrances, and exits”,
    - **AND** (**L-2**): “Consider the use of locomotion aids such as walkers, wheelchairs, and scooters in setting the dimensions of doorways, entrances and pathways”.
        - These guidelines involve the ‘Import Human’ function in an environment. The relevant ICF user activity is ‘Moving Around’. Adjusting the font size and style entails a parametric change. The resulting design rule is (Import Human, Moving Around) → (Parametric).
    - (**L-3**): “Provide adequate seating at regular intervals in public spaces such as parks, airports, and shopping centers”.
        - This guideline involves adding in the functionality to ‘Support Human’ in an environment as users engage in the ‘Moving Around’ activity. This is a functional addition that allows for users to sit down, and thus adds in the user activity of ‘Sitting’. The resulting design rule is (Support Human, Moving Around) → (Functional, Sitting).
    - (**L-4**): “Furniture, shower, and toilet design should assist actions such as sitting down, standing up, getting in and out, by providing grab bars, handles or other means of support”,
    - **AND** (**L-5**): “Design items such as seats, showers, and toilets to assist actions such as sitting down and standing up, or getting in and out, by providing grab bars, handles or other means of support”.
        - These guidelines involve adding in the functionality to ‘Support Human’ in an environment as users engage in the ‘Changing Basic Body Position’ activity. This entails a functional addition, and the resulting design rule is (Support Human, Changing Basic Body Position) → (Functional, Changing Basic Body Position).
    - (**L-6**): “Attempt to integrate grab bars and handles into the overall aesthetic appeal of the design and avoid designs that look ‘medical’ or ‘assistive’”.

        - This guideline involves the ‘Support Human’ function in a product or environment as users perform the ‘Moving Around’ activity. Incorporating grab bars into the overall aesthetic entails a morphological change and the resulting rule is (Support Human, Moving Around) → (Morphological). The user activity in the inclusive design remains the same, or is unspecified, and is thus omitted from the design rule.
    - (**L-7**): Reduce the need to bend the back or reach below waist level for any product interaction.
        - This guideline entails a morphological change, as it suggests using different methods for accomplishing any ‘Interface with Product’ functions that involve the user activity of ‘Bending’. This is not a functional change, as it does not entail the deletion of a function related to a user bending over, but rather entails a change to that function so that the user no longer needs to bend over. The resulting design rule takes the form (Interface with Product, Bending) → (Morphological, Remove Bending Functions).
- Reach and Stretch Design Guidelines
    - (**R-1**): “Allow for single-handed operation where possible, by eliminating the need to reach both hands out simultaneously, and facilitating the option to reach either the left or right arm out to operate a product”.
        - This guideline entails a morphological change, as it suggests using different methods for accomplishing any ‘Position Hand’ functions that involve the user activity of ‘Reaching’, such that the new user activity is ‘Reaching with Single Hand’. The resulting design rule takes the form (Position Hand, Reaching) → (Morphological, Reaching with Single Hand).
    - (**R-2**): “Ensure that products or services that require access by the public are able to cope with the range of heights that people can reach to, including those in wheelchairs”,
    - **AND** (**R-4**): “Consult available data sources on reach ranges when setting the dimensions of products and environments”.

    - These guidelines entail parametric changes, as they suggest varying the parameters for accomplishing any 'Position Hand' functions that involve the user activity of 'Reaching'. There is no change in user activity from typical to inclusive design. The resulting design rule takes the form (Position Hand, Reaching) → (Parametric, Reaching).
  - (**R-3**): "Minimize the need to exert forces with the arms outstretched or, in particular, when reaching over the head".
    - This guideline entails a morphological change, as it suggests using different methods for accomplishing any 'Guide Solid' functions that involve the user activity of 'Reaching', so as to avoid exerting force with the arms outstretched. The new user activity is unspecified, as there are many possible solutions designers could use. The resulting design rule takes the form (Guide Solid, Reaching) → (Morphological).
- Dexterity Design Guidelines
  - (**D-1**): "Consider the compatibility of grip and intended action on the product, to avoid situations where a product requires a certain type of grip or motion that is not compatible with the overall task".
    - This guideline entails a morphological change, as it recommends modifying 'Position Hand' functions that involve the user activity of 'Grasping', so as to ensure grips are compatible with the intended motion. The inclusive user activity is also 'Grasping'. The resulting design rule takes the form (Position Hand, Grasping) → (Morphological, Grasping).
  - (**D-2**): "Attempt to lower all force requirements to operate the product controls (grasping, pushing, pulling, twisting and lifting forces), making allowance for older people and people with disabilities who generally have reduced strength compared to younger and fully able people.
    - This guideline involves the 'Transfer Human Energy' function while the user is performing the any of the user activities that fall under the 'Carrying, Moving, and Handling Objects' user activity category. There are many different ways to lower force requirements, but for the purpose of this

guideline, we have chosen a functional addition assist in exceeding the force requirements. The resulting design rule is (Transfer Human Energy, Carrying, Moving, and Handling Objects) → (Functional). The inclusive user activity is unspecified so as to leave the rule as solution neutral as possible and not limit designers in its application.

- (**D-3**): "Avoid, where possible, controls that require simultaneous manipulations such as pushing and twisting at the same time, such as those often used with dials and bottle caps".
  - This guideline entails a morphological change, as it recommends modifying 'Guide Solid' functions that involve the user activity of 'Manipulating', so as to ensure the user does not have to perform two manipulating actions. The resulting, inclusive, user activity is unspecified, and at the discretion of the designer applying the rule. The resulting design rule takes the form (Guide Solid, Manipulating) → (Morphological).
- (**D-4**): "Utilize pushing in preference to rotating, since for the latter a pincer grip is required in addition to the application of rotational force".
  - This guideline entails a morphological change, as it recommends modifying 'Guide Solid' functions that involve the user activity of 'Turning', so as to instead utilize the 'Pushing' user activity, which allows for an easier grip. The resulting design rule takes the form (Guide Solid, Turning) → (Morphological, Pushing).
- (**D-5**): "Cover surfaces to be gripped with materials that result in adequate friction between the surface of the product handle and the hand, since slippery or smooth surfaces are more difficult to grasp, whereas rubbery and slightly deformable surfaces are easier and more comfortable to hold."
  - This guideline recommends the addition of a 'Secure Hand' function to gripping surfaces, corresponding to the user activity of 'Grasping'. The user activity in the inclusive design is also 'Grasping'. The resulting design rule takes the form (Secure Hand, Grasping) → (Functional, Grasping).

APPENDIX B: ANALYSING MATCHING DESIGN RULES

- ***D-5: (Secure Hand, Grasping) → (Functional, Grasping)***

In Clarkson's work, this guideline suggests the functional addition of a 'Secure Hand' function to ensure that products are easier and more comfortable to hold. A product that may prove difficult to grasp for those with disabilities is a typical box cutter. Users who have trouble with fine hand movement, such as persons suffering from arthritis, are likely to have trouble gripping and controlling the smooth plastic surfaces of a box cutter. As the results of a user's hands slipping while using such a sharp tool are quite severe, it would be very beneficial to develop a more inclusive box cutter design. An image of a box cutter and its associated actionfunction diagram can be seen in Figure 27 and Figure 28, respectively.

Figure 27. Typical Box Cutter

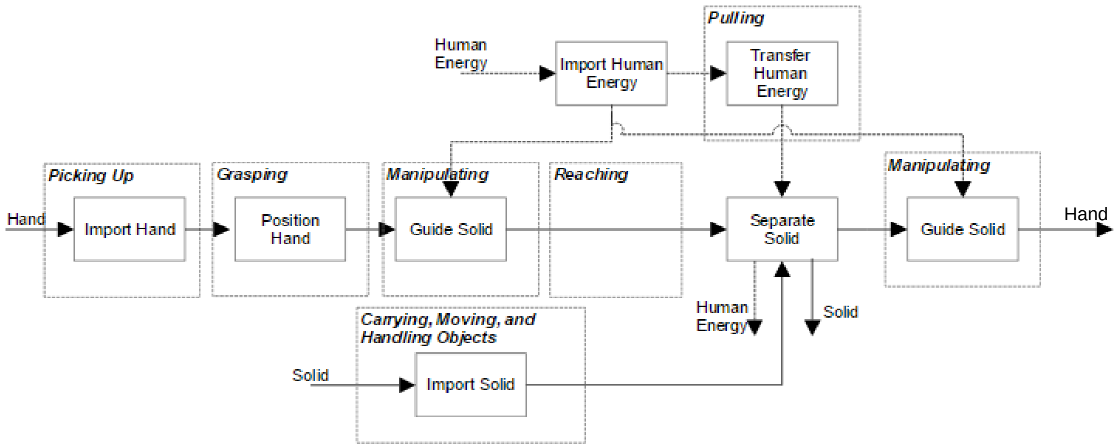


Figure 28. Actionfunction Diagram of Typical Cutter

Applying Clarkson's guideline of "Cover surfaces to be gripped with materials that result in adequate friction between the surface of the product handle and the hand", we obtain the actionfunction diagram in Figure 29.

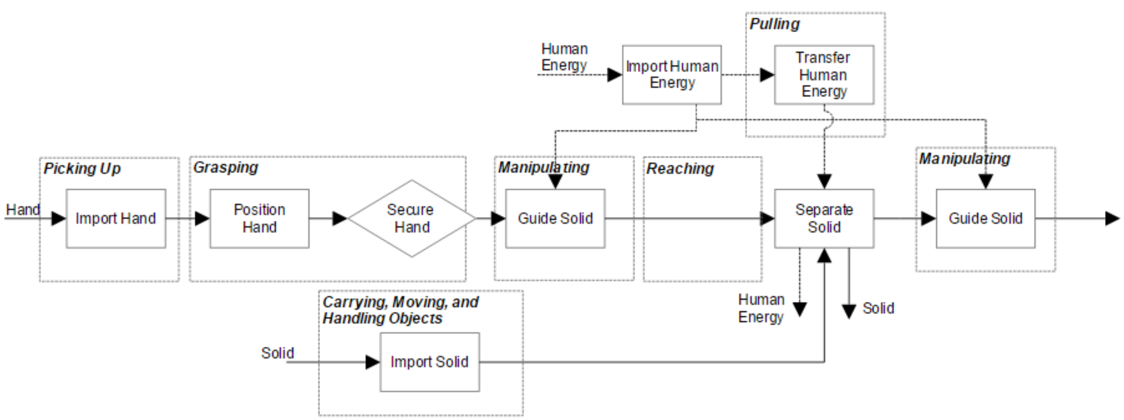


Figure 29. Box Cutter Actionfunction Modified Using Clarkson's Rule

In the association rule format, this guideline does not suggest any changes to the 'Position Hand' function under the 'Grasping' user activity. However, in the sentence format mentioned above, the design guideline implies that the 'Secure Hand' function needs to be added to aid in the 'Position Hand' function. Applying Clarkson's suggested design changes results in the addition of the 'Secure Hand' function to the 'Grasping' user activity. The resultant inclusive actionfunction diagram closely mirrors the functionality of the SLICE ceramic box cutter, in Figure 30, and thus proves to have a meaningful result. The SLICE ceramic box cutter has a curved, nonslip finger grip to secure the cutter in the user's hand.

Figure 30. SLICE Box Cutter

Applying Sangelkar's design rule of (Secure Hand, Grasping) → (Functional, Grasping) to the typical box cutter actionfunction diagram yields similar results. Sangelkar's research suggested the Fisker Rotary Cutter as an inclusively designed alternative to the typical box cutter. The actionfunction diagram of this inclusive box cutter can be seen in Figure 32. Note that this actionfunction diagram suggests the functional addition of the 'Secure Hand' function under the 'Grasping' user activity, matching the results of applying Clarkson's related design guideline. There are additional changes to different functions, but we are just comparing the effects of applying this singular rule.

Figure 31. Fisker Rotary Cutter [2]

The results of applying the same design rule from Clarkson's and Sangelkar's rule sets match very closely. Both rules lead to the functional addition of a 'Secure Hand' function under the 'Grasping' user activity. Because Sangelkar's actionfunction diagram is derived from comparing an inclusive design to typical design, there are multiple changes outside of the studied rule of (Secure Hand, Grasping) → (Functional, Grasping). However, we are only studying the effect of applying this one rule, so we say that the effects are the same.

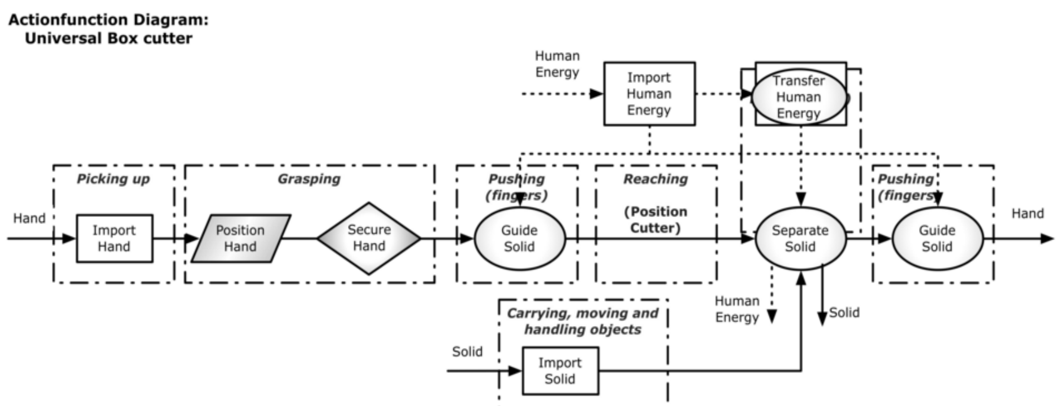


Figure 32. Box Cutter Actionfunction Modified Using Sangelkar's Rule [2]

- ***R-2,4: (Position Hand, Reaching) → (Parametric)***

In Clarkson's work, this guideline suggests modifying the user activity of 'Reaching', as designers should consider all ranges of reach in designing a product. A product that requires a significant reach is a typical showerhead setup. For many, it is difficult to reach for and control a handheld showerhead due to factors limiting their reach. The actionfunction diagram of a typical showerhead can be seen in Figure 34.

Figure 33. Typical Handheld Shower Head

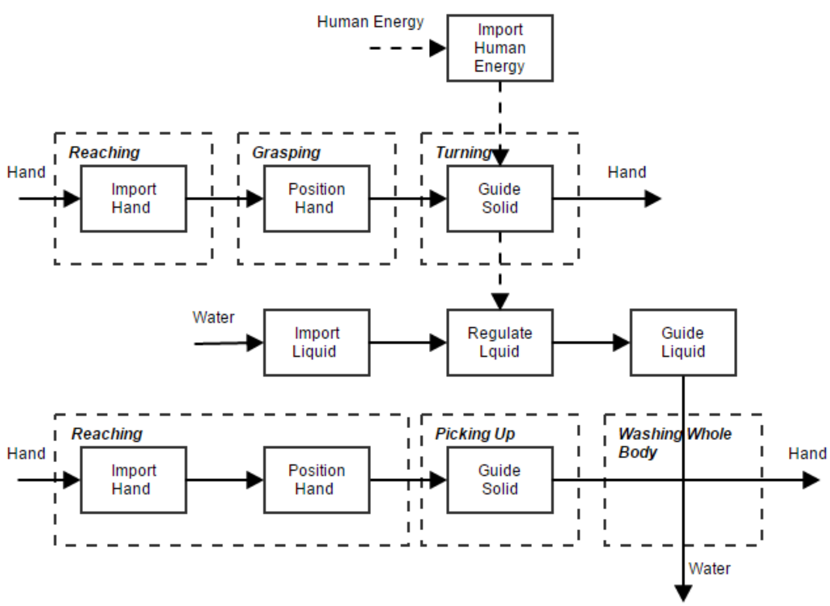


Figure 34. Actionfunction Diagram of Typical Shower Head

Applying Clarkson's guideline of "Cover surfaces to be gripped with materials that result in adequate friction between the surface of the product handle and the hand", we obtain the actionfunction diagram in Figure 35.

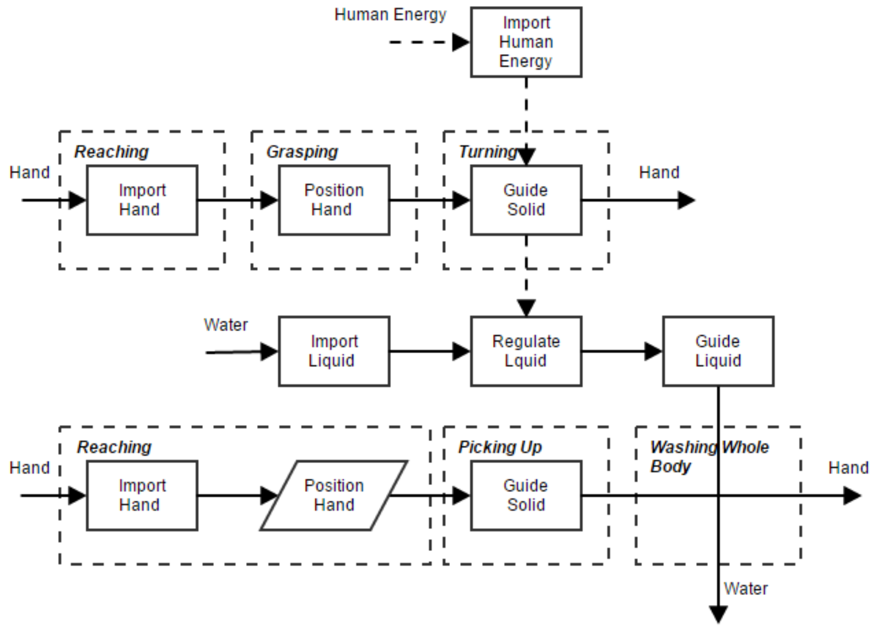


Figure 35. Shower Head Actionfunction Modified Using Clarkson's Rule

The modified actionfunction diagram of Figure 35 reflects the parametric change to the 'Position Hand' function under 'Reaching', corresponding to a change in dimensions/location of the shower head. The resultant inclusive actionfunction diagram resembles a disabled showerhead, and thus proves to be meaningful. Many disabled showers have the showerhead at a much lower height, allowing easier reach for any user. Whether a user is disabled or not, they will have a much easier time of reaching the shower head when it is placed at a much lower height.

Applying Sangelkar's design rule of (Guide Solid, Twisting) → (Morphological, Pushing) to the typical showerhead yields the same results as applying Clarkson's design guideline. The results of modifying the typical showerhead actionfunction diagram using the aforementioned rule from Sangelkar's rule set can be seen in Figure 36. Sangelkar's design rule suggests a parametric change to the 'Position Hand' function in the typical showerhead actionfunction diagram, signifying to the designer that parametric changes, such as changes to the height or size of the shower head, will lead to a more inclusive product.

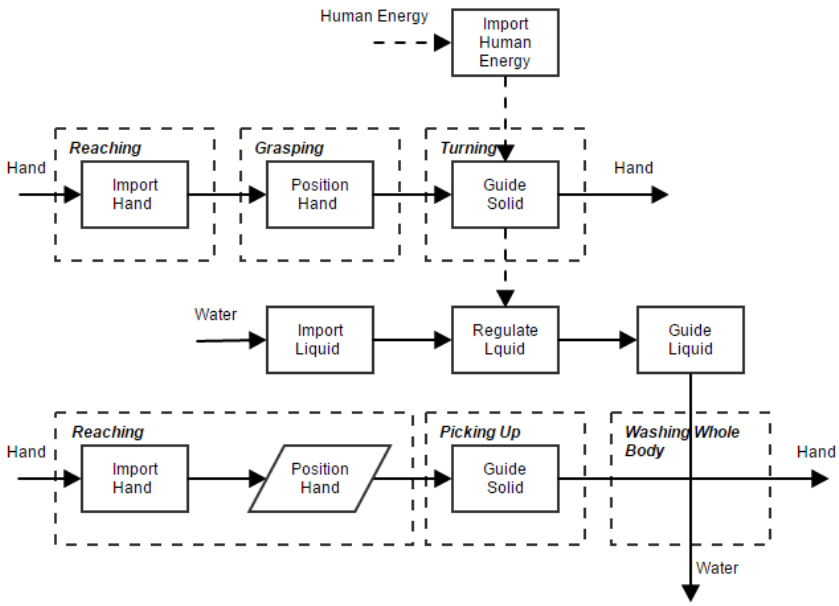


Figure 36. Shower Head Actionfunction Modified Using Sangelkar's Rule

- ***L-1,2: (Import Human, Moving Around) → (Parametric)***

In Clarkson's work, this guideline suggests modifying the dimensions of doorways and entrances to ensure that all users can easily enter and exit. A typical product that involves entering and exiting is a door. While many doorways today are dimensioned properly to be inclusive to all users, designers should always keep this guideline in mind so as to not exclude any potential users. The actionfunction diagram of a typical door can be seen in Figure 38.

Figure 37. Typical Door

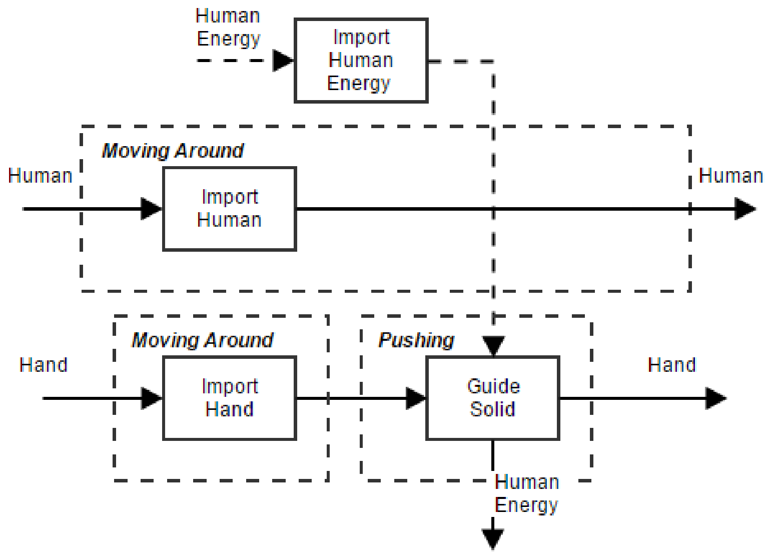


Figure 38. Actionfunction Diagram of Typical Door

Applying Clarkson's guideline of "[a]ttempt to provide adequate space for access and egress when designing doorways, entrances, and exits", we obtain the actionfunction diagram in Figure 39.

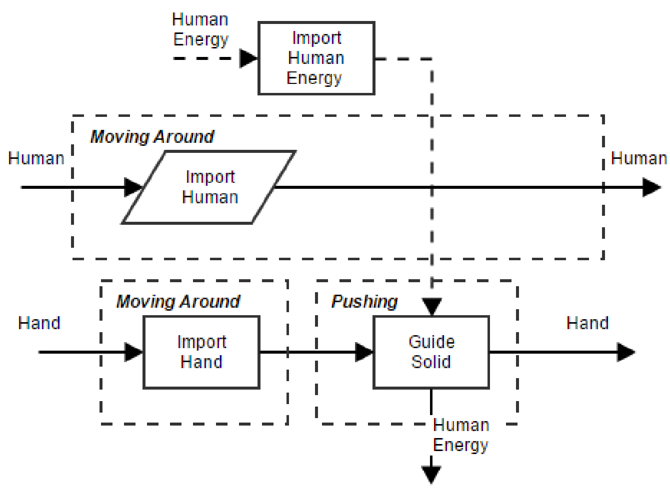


Figure 39. Door Actionfunction Modified Using Clarkson's Rule

The modified actionfunction diagram of Figure 39 reflects the parametric change necessary in the 'Import Human' function to make the doorway more accessible. The resultant inclusive actionfunction diagram mirrors that of wider doors that are more accessible to users of all dimensions, and would even allow the transfer of locomotion aids through. The doorway could be designed to be even more inclusive, similar to an automated disability door, however we are only looking at the application of this one rule.

Applying Sangelkar's design rule of (Import Human, Moving Around) → (Parametric, Moving Around) to the typical door yields the same results as applying Clarkson's design guideline. The results of modifying the typical door actionfunction diagram using the aforementioned rule from Sangelkar's rule set can be seen in Figure 40. Sangelkar's design rule suggests a parametric change to the 'Import Human' function in the typical door actionfunction diagram, signifying to the designer that parametric changes, such as changes to the height or width of the door, will lead to a more inclusive product.

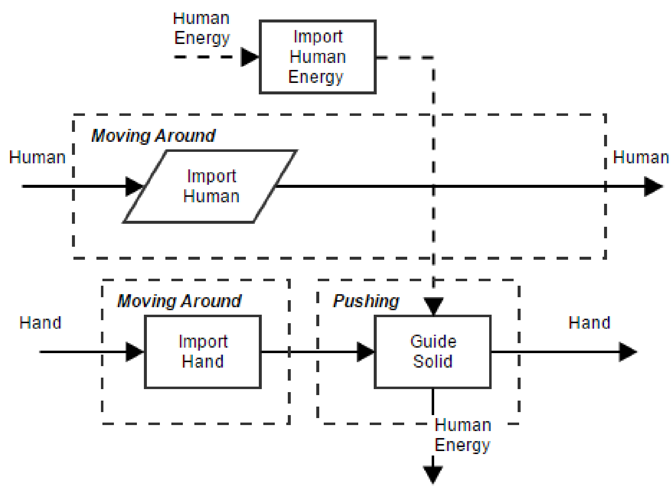


Figure 40. Door Actionfunction Modified Using Sangelkar's Rule

- ***V-1,2,3: (Indicate Status, Communication – Written) → (Parametric)***

  In Clarkson's rule set, this rule comes from the guideline that designers should attempt to make text as large as possible, maximize contrast between text and its background, and forego decorative fonts for more legible, sans-serif fonts. These guidelines are all focused on creating products that all users will be able to read, regardless of their level of sight. A typical product that relies heavily on communicating information to users by means of written information is a warning sign. Signs that have too small text, or poor contrast between text and its background do not properly convey their message to users with diminished eyesight. Consider the following actionfunction diagram for a typical warning sign.

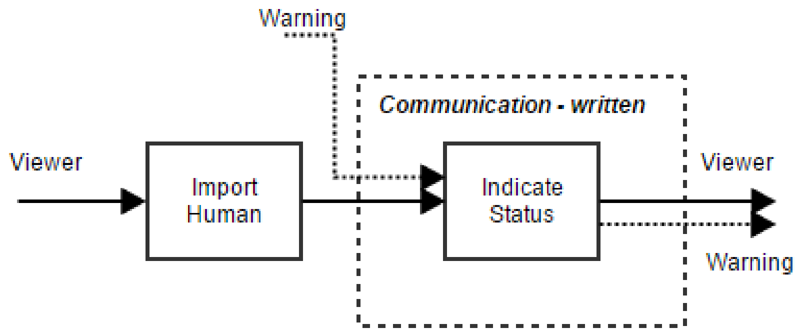


Figure 41. Actionfunction Diagram of Typical Warning Sign

Applying the matching design rules to this actionfunction diagram yields the modified actionfunction diagram of Figure 42.

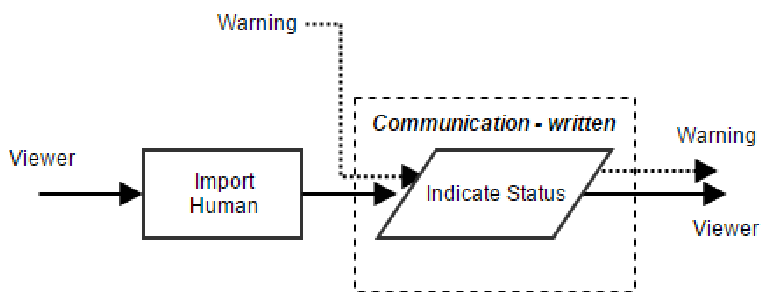


Figure 42. Actionfunction Diagram Modified by (Indicate Status, Communication – Written) → (Parametric)

The application of these rules suggest to designers that they need to consider parametric changes, such as changes to font size and color, when designing products that communicate written information. In regards to the typical warning sign, designers should ensure that text is large enough and stands out enough to convey the meaning clearly to all potential readers.

- ***V-7,8,9,10: (Indicate Status, Seeing Functions) → (Morphological, Seeing Functions)***

In Clarkson's work, this design rule stems from guidelines suggesting different methods to make screens, such as those on computers, easier to read. Designers should "[a]ttempt to avoid shiny and highly reflective surfaces" and allow for more easily repositioned light sources. Additionally, designers should consider "providing displays and screens that can easily be repositioned" [15]. Consider a typical computer screen. All users, regardless of disability and seeing ability, would have trouble viewing a screen that is obscured by glare. The actionfunction diagram of a typical screen is pictured in Figure 43.

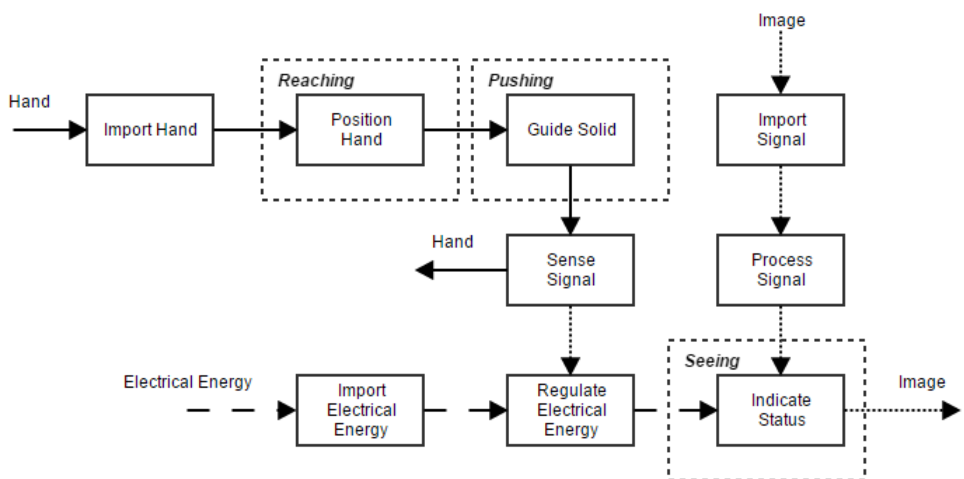


Figure 43. Actionfunction Diagram of Typical Screen

Figure 44. Typical Computer Screen

Applying the matching design rules of (Indicate Status, Seeing Functions) → (Morphological, Seeing Functions) results in the modified actionfunction diagram of Figure 45. These matching design rules suggest a morphological change, a change to how the 'Indicate Status' is physically solved. Such changes could include utilizing a special type of polarized screen, a matte cover, or designing in special shades to block outside light sources. For the purpose of this example, we have chosen to add a glare-reducing polarized screen in order to make for easier viewing.

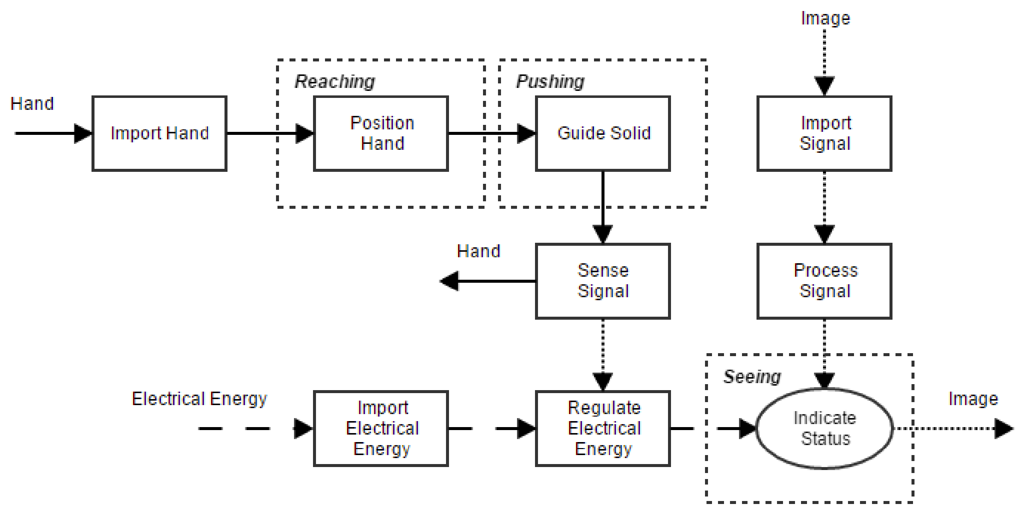


Figure 45. Screen Actionfunction Modified with (Indicate Status, Seeing Functions) → (Morphological, Seeing Functions)

Figure 46. Anti-glare Screen Modification

APPENDIX C: ANALYZING SIMILAR DESIGN RULES

- ***D-3: (Guide Solid, Manipulating) → (Morphological)***

In Clarkson's guidelines, this rule is expressed as a need to "avoid…controls that require simultaneous manipulations such as pushing and twisting at the same time…" [6]. A typical product that exhibits simultaneous manipulations is a pill bottle. The typical pill bottle requires simultaneous pushing and twisting to disengage the bottle cap, an action that is difficult for users without full ability in their hands. An actionfunction diagram for a typical pill bottle cap can be seen in Figure 48.

Figure 47. Typical Pill Bottles

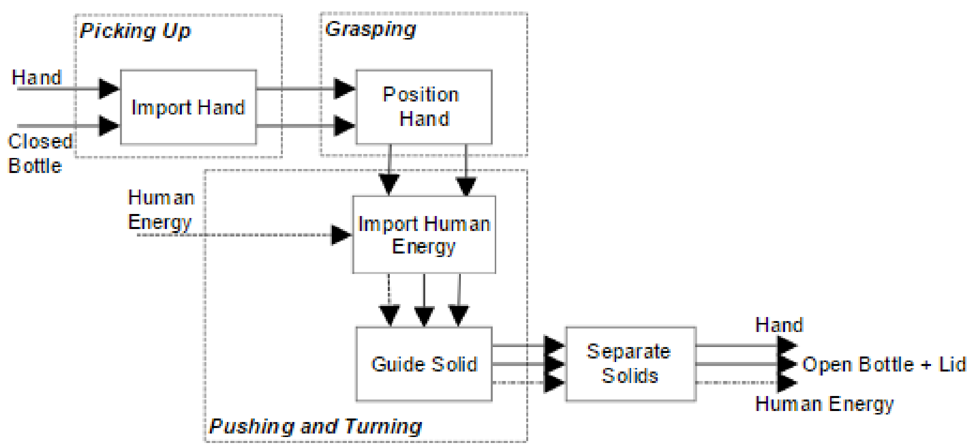


Figure 48. Actionfunction Diagram of Typical Pill Bottle Cap

Applying Clarkson's guideline to eliminate simultaneous manipulations yields the modified actionfunction in the figure below.

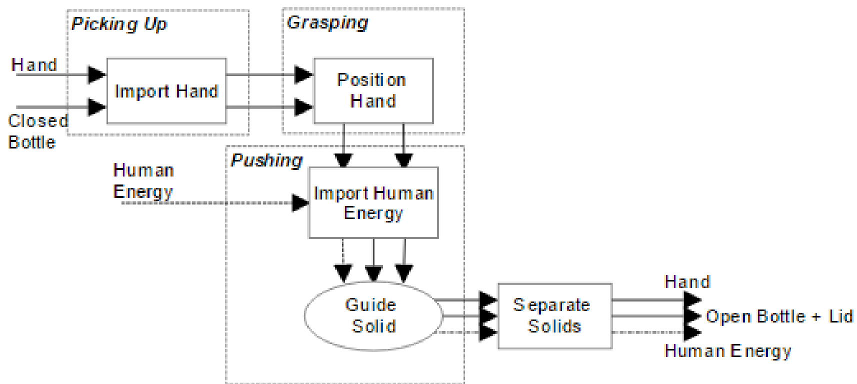


Figure 49. Pill Bottle Actionfunction Modified Using Clarkson's Rule

The modified actionfunction diagram of Figure 49 reflects the morphological change to change the 'Guide Solid' user activity from 'Pushing and Twisting' to just 'Twisting'. The resultant inclusive actionfunction diagram closely mirrors how the Aleve Easy Open Arthritis Cap functions, and has a meaningful result The Aleve Easy Open Arthritis Cap soft-grip cap does not have a child resistant feature. Because of this, the cap can be removed by simply twisting, rather than pushing and twisting, and is much more inclusive to users without full functionality of their hands.

Figure 50. Aleve Easy Open Cap

Applying Sangelkar's design rule of (Guide Solid, Manipulating) → (Morphological) to the typical pill bottle yields the same results as applying Clarkson's design guideline. The results of modifying the typical pill bottle actionfunction diagram using the (Guide Solid, Manipulating) → (Morphological) rule from Sangelkar's rule set can be seen in Figure 41. Sangelkar's design rule suggests a morphological change to the 'Guide Solid' function in the typical pill bottle's actionfunction diagram, signifying to the designer that morphological changes, such as changes to how the pill bottle cap is disengaged from the pill bottle, will lead to a more inclusive product.

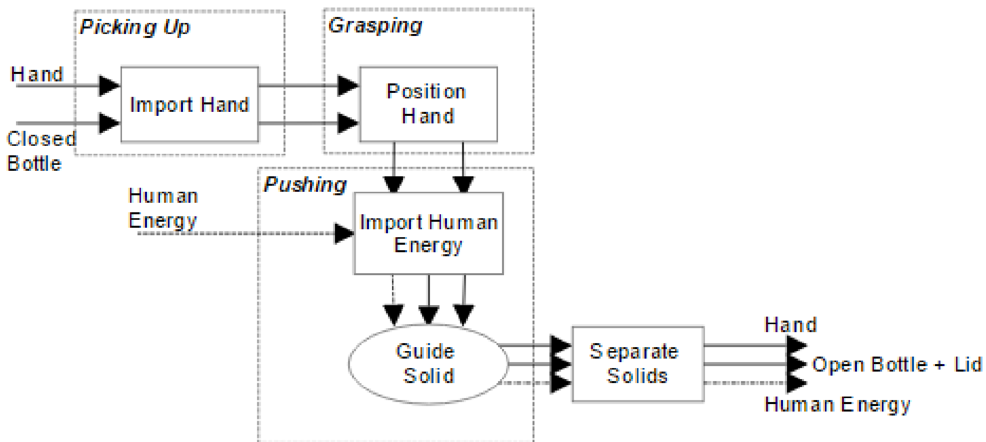


Figure 51. Pill Bottle Actionfunction Modified Using Sangelkar's Rule

In this case, the results of Sangelkar's rule match those of Clarkson's guideline; both rules suggesting a morphological change to how the user opens the bottle.

- ***2. Clarkson: (Support Human, Changing basic body position) → (Functional, Grasping) vs. Sangelkar: (Guide Human, Sitting) → (Functional, Grasping) AND (Guide Human, Standing) → (Functional, Grasping)***

In Clarkson's guidelines, this rule is expressed as a need to "[d]esign items such as seats, showers, and toilets to assist actions such as sitting down and standing up" [1]. As stated in the guideline, a typical product relating to these changes is a toilet. A toilet does not have any grips or supports in its typical configuration, which makes it very difficult for less able users to stand up without assistance. An actionfunction diagram for a typical toilet can be seen in Figure 52.

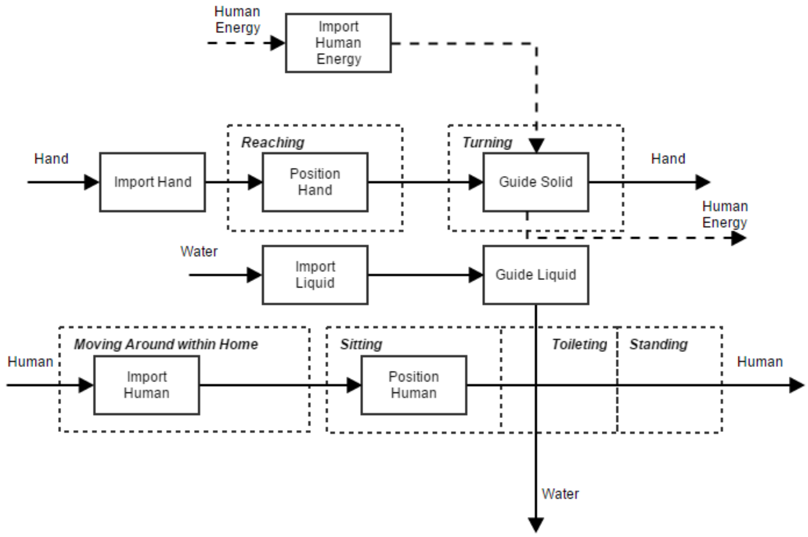


Figure 52. Actionfunction Diagram of Typical Toilet

Applying Clarkson's guideline to the typical toilet entails the addition of multiple functions with the goal of securing the user when they sit down on, and stand up from, the toilet. As Clarkson's guideline suggests, we have added in the 'Support Human' function to both the 'Sitting' and 'Standing' user activities. To accompany this addition, we have also added in 'Grasping' user activities with the function 'Position Hand' to model how a user would interact with the grips by grasping them. These functional additions create a more inclusive product, as the modified toilet now provides a means to support the user while they are sitting on or standing up from the toilet.

Figure 53. A Toilet with Rails, Physical Representation of Clarkson's Changes

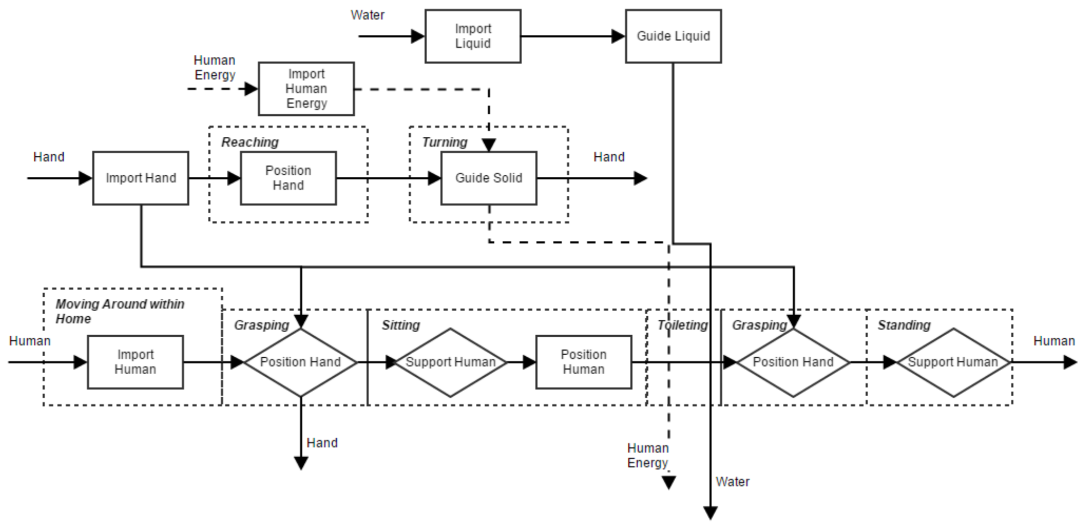


Figure 54. Toilet Actionfunction Modified Using Clarkson's Rules

The actionfunction diagram of Figure 54 can be physically represented by a toilet with attached support rails. These rails allow for any user to safely sit or stand without being inconvenienced. Combining this Clarkson guideline with Clarkson guideline L-6 would lead towards the design of toilets, or any other product requiring sitting and standing, that incorporated grips and supports into the overall design aesthetic, thereby creating more inclusive toilets while ensuring that the included rails are not obtrusive.

Applying Sangelkar's similar guideline to the typical toilet yields a similar result. Sangelkar's rule entails a similar functional addition of 'Guide Human' function under the 'Sitting' and 'Standing' user activity, which then leads to additions of 'Grasping' user activities with the function 'Position Hand' to model how a user would interact with the grips by grasping them. These changes lead designers to add in features that guide the users into a seated (or standing) position. The resulting toilet actionfunction diagram can be seen in Figure 55.

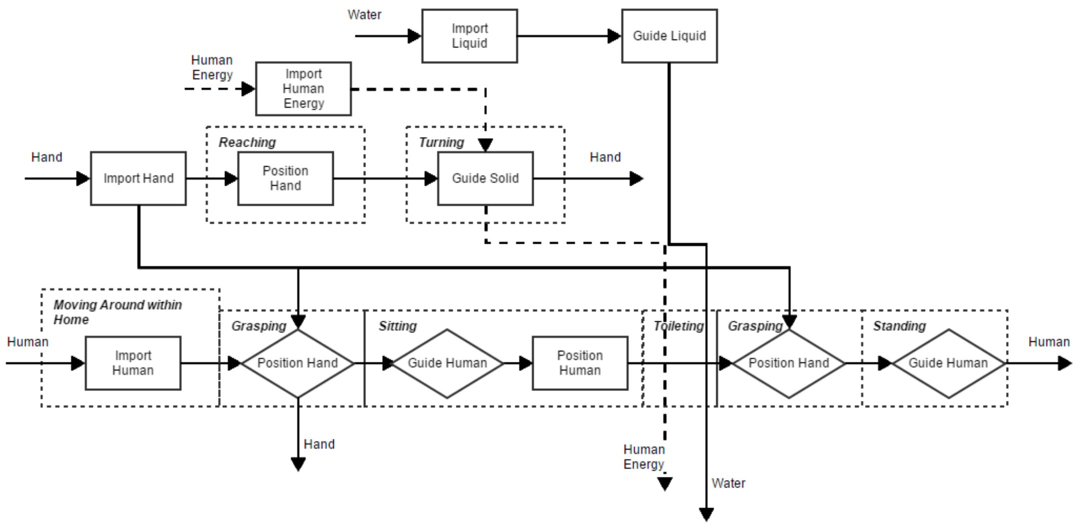


Figure 55. Toilet Actionfunction Modified Using Sangelkar's Rule

The functional changes suggested by Sangelkar's design rule assist users in sitting down and standing up from the toilet. The 'Guide Human' functions lead to solutions that could involve actively aiding the user sit or stand, rather than the passive support in 'Support Human' functions from Clarkson's guideline. Such solutions could include hydraulically or pneumatically actuated pistons that raise or lower the seat as the user stands or sits. Depending on the type of solution, additional functions, representative of the specific solution, will be added in to the actionfunction diagram of Figure 56. A physical representation of such a solution is the Stand-Up Toilet, designed by Zhu Zhongyan and Zhou Jingwen.The Stand-Up toilet features a hydraulically actuated seat that aides the user in standing up and sitting down.

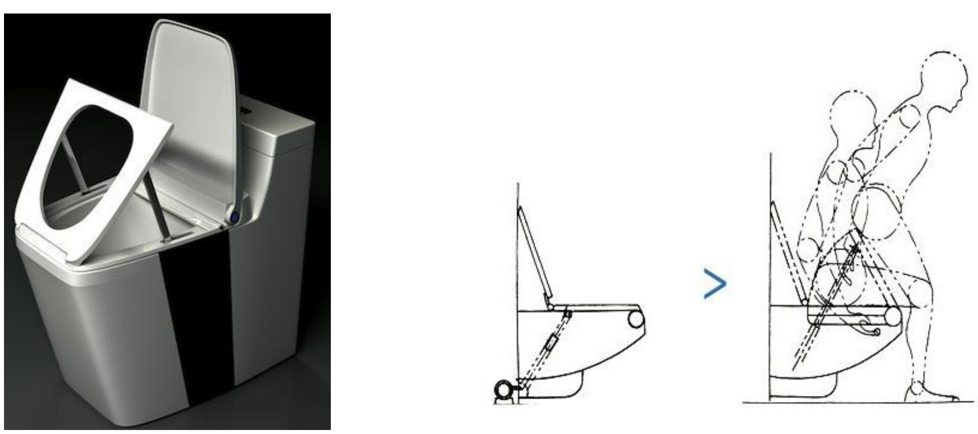


Figure 56. Physical Representation of Toilet Modified by Sangelkar's Rule

In this instance, the functional addition of 'Guide Human' from applying Sangelkar's rule is more inclusive than the functional addition of 'Support Human' from applying Clarkson's rule. This is because the 'Guide Human' function added by applying Sangelkar's rule provides active assistance as the user stands or sits, whereas the 'Support Human' function from Clarkson's guideline is more passive.

- ***3. Clarkson: (Indicate Status, Perceptual Functions) → (Morphological, Communication - various) AND (Indicate Status, Communication - nonverbal) → (Morphological, Communication - various) vs. Sangelkar: (Indicate Status, Communication – written) → (Morphological, Communication – braille)***

In Clarkson's guidelines, these rules are expressed as a need to provide the potential for communication to be accomplished by secondary, alternative methods, so as to include users who may be challenged understanding one mode of communication. Sangelkar's similar rule expresses the same intent, the need to provide secondary communication modes in case the primary mode of communication excludes users. However, Sangelkar's rule only pertains to adding braille communication to written messages; Clarkson's similar guidelines are more generalized and span a much broader scope of communication functions. A control panel is a typical environment that could exclude users due to communication issues.

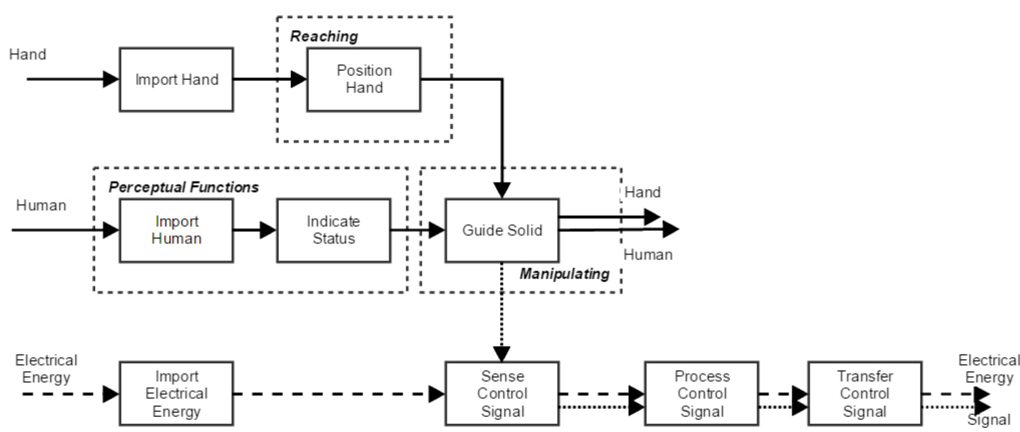


Figure 57. Actionfunction Diagram of Typical Control Panel

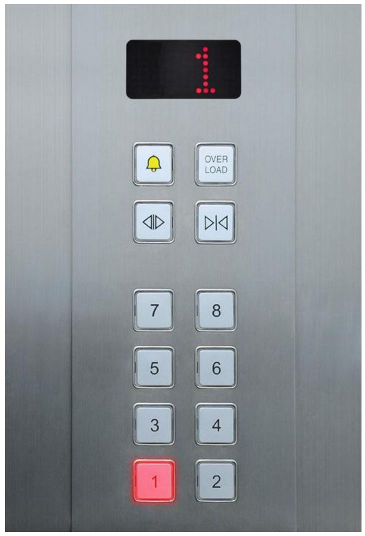


Figure 58. Typical Elevator Control Panel

Applying Clarkson’s guideline to the typical elevator control panel entails a morphological change to the ‘Indicate Status’ function under the ‘Communication – nonverbal/written’ user activity with the goal of providing secondary media through which to communicate the controls’ status to the user. This morphological modification creates a more inclusive product, as the modified control panel now provides the ‘Indicate Status’ function in a ‘Communication – multiple modes’ user activity. This ‘Communication – multiple modes’ user activity would lead a designer to develop products with alternative modes of communication to indicate the product status to a user who may be excluded from a particular mode of communication. These solutions could include braille embossing, picture representation of the floors, or even audio cues from a speaker.

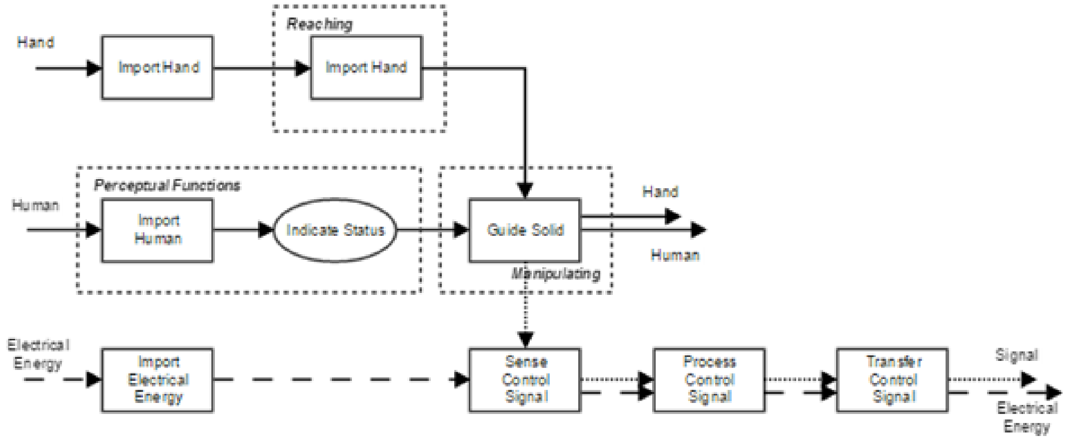


Figure 59. Control Panel Actionfunction Modified Using Clarkson's Rules

The actionfunction diagram of Figure 59 can be physically represented by an elevator control panel with braille embossing or a voice-alert system. These extra modes of communication help to make the control panel more inclusive for users who may have diminished eyesight. There are many different modes of communication that designers could choose for their solutions, from special displays to descriptive images for each button – Clarkson's rule allows a very broad range of potential solutions that designers can choose from to make their control panels more inclusive.

Figure 60. A Physical Representation of Clarkson's Changes to the Control Panel

Applying Sangelkar's similar guideline to the typical control panel yields a similar result. Sangelkar's rule entails a modification of the 'Indicate Status' function, changing the associated user activity from 'Communication-written' to include 'Communication-braille'. These changes lead designers to add in braille embossing to provide an additional source of information for less abled users. The resulting control panel actionfunction diagram can be seen in Figure 61.

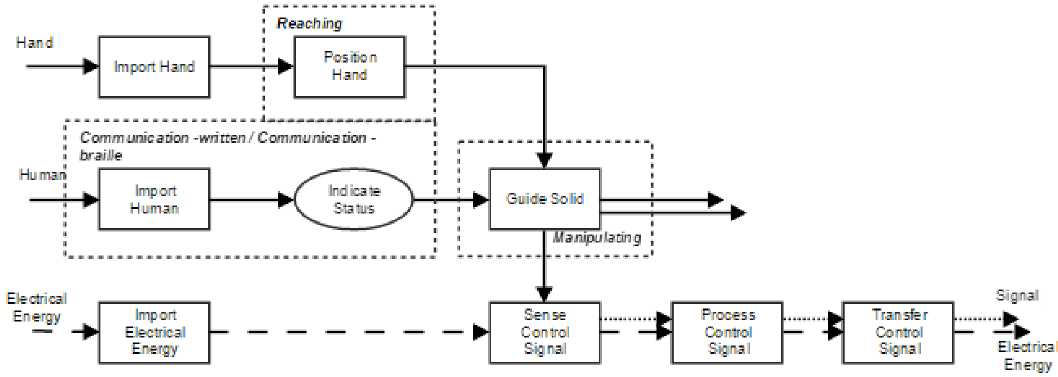


Figure 61. Control Panel Actionfunction Modified Using Sangelkar's Rule

The morphological changes suggested by Sangelkar's design rule assist users in reading the information the control panel and developing a correct mental model for how the system works. The changed 'Indicate Status' functions leads to solutions involving braille embossing, allowing for a more inclusive product for those with disabilities of the eyes. The resulting actionfunction diagram could be physically represented by the braille control panel in Figure 62.

Figure 62. Physical Representation of Sangelkar's Control Panel

In this instance, the morphological changes provided by Clarkson's design rule are more inclusive than those provided by Sangelkar's design rule. Clarkson's changes lead to multiple methods of communication, such as such as descriptive images or lights for each button or braille. Sangelkar's design rule only leads to the modification of adding in braille as an additional form of communication. While both design rules lead to more inclusive products, the multiple methods of additional communication that Clarkson's rule suggests reaches a larger range of disabled users than the single method of braille from Sangelkar's design rule.

- ***4. Clarkson: (Export Signal, Hearing Functions) → (Parametric) vs. Sangelkar: (Indicate Status, Hearing Functions) → (Parametric)***

Here, Clarkson's rule of (Export Signal, Hearing Functions) → (Parametric, Hearing Functions) stems from the need for designers to make products' volume levels adjustable and to keep frequencies in an audible range. Sangelkar's rule stems from a similar need adjust the parameters of 'Indicate Status' functions in products in order to lead to a more inclusive product. The parametric changes could include changes to product volume, pitch, or tone duration. These two rules are very similar, the only difference is that Clarkson's rule involves the 'Export Signal' function, which is slightly more general than the 'Indicate Status' function of Sangelkar's rule. A typical product that would relate to these rules is a speaker or an auditory sign. The typical actionfunction for a speaker can be seen in Figure 63.

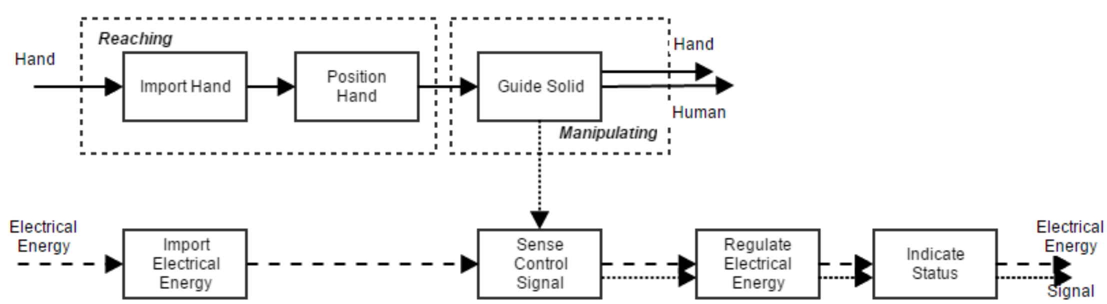


Figure 63. Actionfunction Diagram for Typical Electronic Speaker

Figure 64. Example of a Typical Electronic Speaker

Applying Clarkson's rule of (Export Signal, Hearing Functions) → (Parametric) yields the actionfunction diagram of Figure 65. Applying this design rule requires the designer to infer off of the typical product's actionfunction diagram, as there is not an 'Export Signal' function explicitly present. However, the 'Indicate Status' function also involves exporting a signal, and we can modify it with the same design rule.

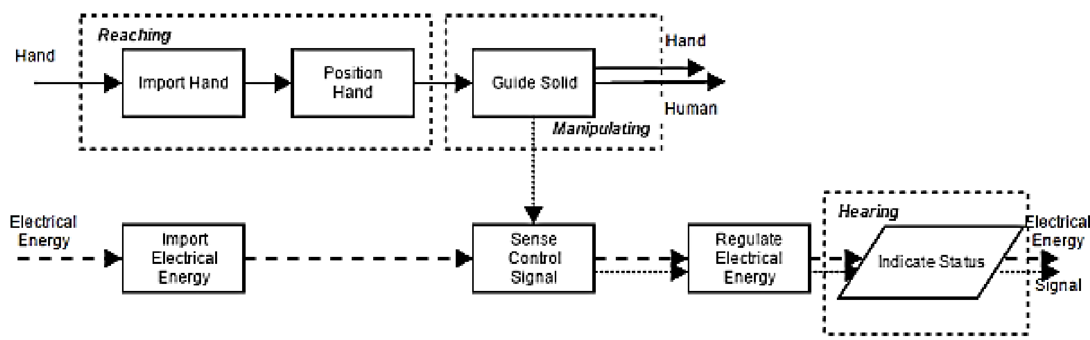


Figure 65. Speaker Actionfunction Modified by Clarkson's Rule

The physical representation of Clarkson's modified speaker would be the same as the typical speaker, but now with an adjusted volume and/or frequency range. If we were also to include the attached rule, suggesting a functional addition so the user may adjust the volume would add in an extra 'Adjust Signal' function.

Applying Sangelkar's design rule of (Indicate Status, Hearing Functions) → (Parametric) has the same results as applying Clarkson's rule, however in this case, without the need for any inference. Sangelkar's rule suggests a parametric change to the 'Indicate Status' function, suggesting some change to the parameters of the speaker noise. This could lead to modifications to speaker tone, frequency, and volume that would make the speaker easier to listen to for all users. The resulting actionfunction diagram can be seen in Figure 66.

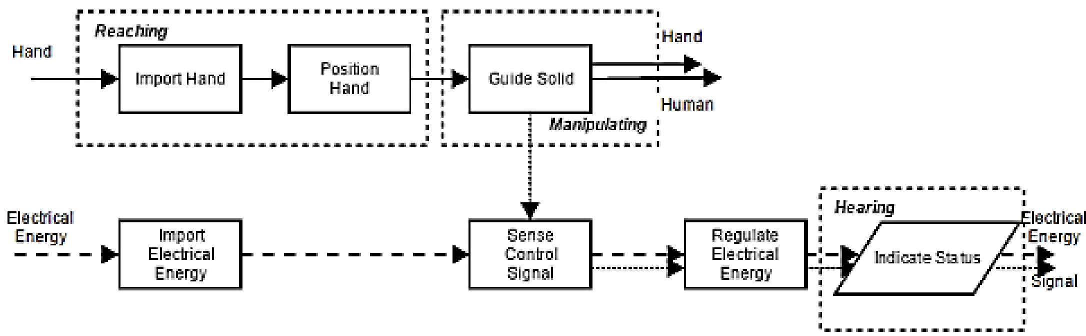


Figure 66. Speaker Actionfunction Modified by Sangelkar's Rule

In this instance, the application of Clarkson's and Sangelkar's similar design rules have the same results. However, there were differences in implementation. Clarkson's rule required some interpretation because it involved the 'Export Signal' function rather than the 'Indicate Status' function that was present in the speaker. This is an issue of phrasing, as both the 'Export Signal' and 'Indicate Status' functions serve the same purpose of creating a noise for the user to listen to. The application of these rules to the typical speaker yields a viable, more inclusive product, and thus these rules could be said to be effective.

- ***5. Clarkson: (Export Signal, Hearing Functions) → (Morphological, Hearing Functions) vs. Sangelkar: (Indicate Status, Hearing Functions) → (Morphological)***

In Clarkson's rule set, this rule stems from the guideline to "[a]void synthesized speech in favor of natural speech … and use lower pitched voices in preference to higher pitched voices" [15]. Likewise, Sangelkar's similar rule stems from a similar need for morphological changes to the 'Indicate Status' functions of products that users listen to. A typical product that would relate to these guidelines is a public address (PA) system. The PA system has a very similar actionfunction diagram to the speaker, above in Case 4, and its actionfunction diagram, corresponding to how a listener interacts with the PA system, is pictured below in Figure 67.

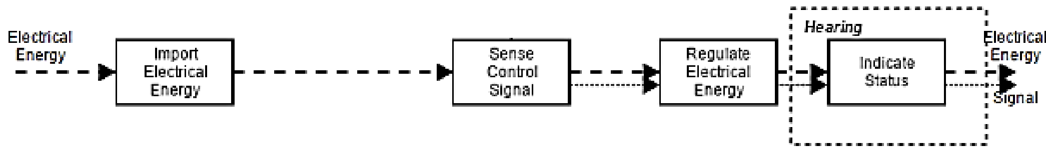


Figure 67. Typical Public Address System Actionfunction Diagram

Figure 68. Speakers of Public Address System

Applying Clarkson's guideline of (Export Signal, Hearing Functions) → (Morphological, Hearing Functions) yields the actionfunction diagram of Figure 69. As in Case 4, applying Clarkson's design rule requires some degree of inference, as the 'Export Signal' function in Clarkson's rule is not present in the typical product actionfunction. However, the 'Export Signal' function is very closely related to the 'Indicate Status' function, as both relate to how a signal is played for users. Because these two functions are so similar, we treat the 'Indicate Status' function in the PA system's actionfunction diagram the same as we would treat the 'Export Signal' function referenced in Clarkson's design rule.

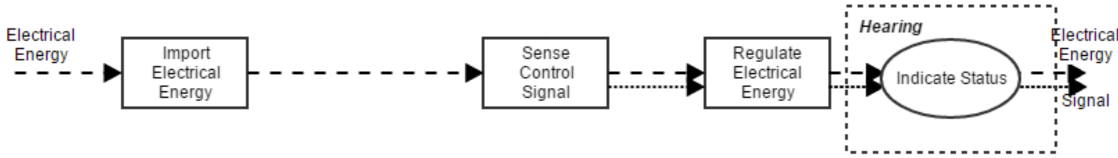


Figure 69. Public Address System Actionfunction Modified by Clarkson's Rule

The morphological changes to the PA system's 'Indicate Status' includes many changes to how the 'Indicate Status' function is physically accomplished. In the case of a public access system, it would be useful for designers to choose a pre-recorded human voice as the solution to the 'Indicate Status' function. This is because a natural human voice is much easier to understand than a computer generated voice, which has an unfamiliar cadence and tone. A PA system that has been modified by Clarkson's design rule would have the same general physical form as the typical PA system, although the system would utilize a human voice in order to be more inclusive.

Applying Sangelkar's design rule of (Indicate Status, Hearing Functions) → (Morphological) has very similar results. Because the 'Indicate Status' function, referenced in Sangelkar's design rule, is present in the typical PA system's actionfunction diagram, there is no need for the designer to infer in order to apply this rule. Applying Sangelkar's design rule yields the actionfunction diagram of Figure 70.

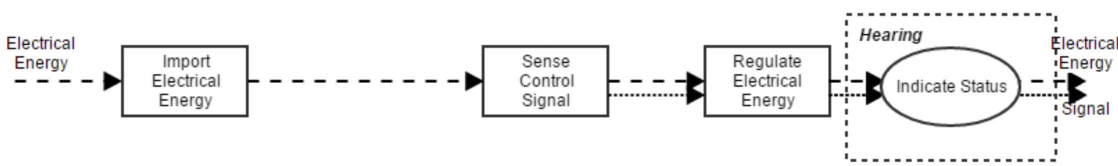


Figure 70. Public Address System Actionfunction Modified by Sangelkar's Rule

The suggested morphological change entails a change to how the 'Indicate Status' function is physically accomplished, including the pre-recorded human voice change suggested by Clarkson's rule. As Sangelkar's rule does not specify a typical user activity, there are many possible solutions, such as utilizing a scrolling sign (Figure 71) so that users with impaired hearing would be able to read a message instead of listening (therefore changing the user activity to 'Communication – written').

Figure 71. Example of Modified Product by Sangelkar's Proposed Change

Applying Sangelkar's design rule yields very similar results to applying Clarkson's rule. The only difference is that Clarkson's rule specifies that the inclusive user activity remain 'Hearing Functions', whereas Sangelkar's rule does not designate an inclusive user activity. Clarkson's rule is more constrained, however, the constraint allows for a much easier implementation, as the designer applying the rule does not need to think of a new solution to the 'Indicate Status' function. Sangelkar's rule is less constrained, and thus can lead to a wider possible array of inclusive solutions in this situation.

- ***6. Clarkson: (Indicate Status, Communication - nonverbal) → (Parametric) vs. Sangelkar: (Indicate Status, Seeing Functions) → (Parametric)***

Clarkson's rule of (Indicate Status, Communication - nonverbal) → (Parametric) is very similar to the (Indicate Status, Communication – Written) → (Parametric) rule in the matching design rules section. The only difference is that this design rule deals with reading charts and images instead of text. This rule is also similar to Sangelkar's design rule of (Indicate Status, Seeing Functions) → (Parametric), the only difference is that Sangelkar's design rule references the 'Seeing Functions' user activity instead of the 'Communication – nonverbal' activity in

Clarkson's design rule. The 'Seeing Functions' activity includes all activities related to seeing, and thus encompasses the 'Communication – nonverbal' activity, making these two design rules similar. A typical product relating to these rules would be a chart or informative display, the actionfunction diagram of which is pictured in Figure 72.

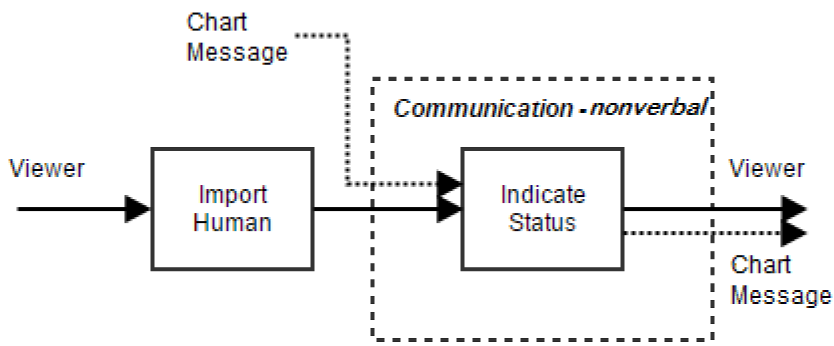


Figure 72. Actionfunction Diagram of Typical Chart

Applying Clarkson's design rule here results in a parametric change to the 'Indicate Status' function under the 'Communication – nonverbal' user activity. There are many parameters a designer could change to make a chart more easy to view, and thus more inclusive. These changes could be changes to the size and contrasts of images, or ensuring that the color palette is appropriate for colorblind users. The modified actionfunction diagram from applying Clarkson's rule of (Indicate Status, Communication - nonverbal) → (Parametric) can be seen in Figure 73.

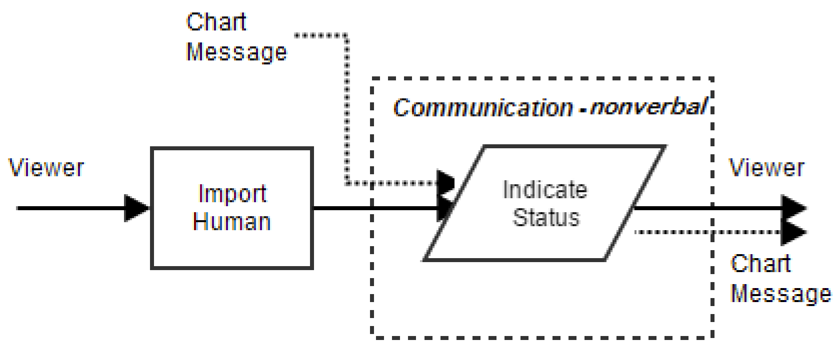


Figure 73. Actionfunction Diagram of Chart Modified by (Indicate Status, Communication - nonverbal) → (Parametric)

Applying Sangelkar's design rule leads to a very similar result. The rule of (Indicate Status, Seeing Functions) → (Parametric) leads to a parametric change to the 'Indicate Status' function under the 'Communication nonverbal' user activity. This is because nonverbal communication, i.e. reading images, falls under the category of sight functions. Just as in the Clarkson modified design, there are many parameters a designer could change to make a chart more easy to view, and thus more inclusive. The modified actionfunction diagram from applying Sangelkar's rule of (Indicate Status, Seeing Functions) → (Parametric) can be seen in Figure 74.

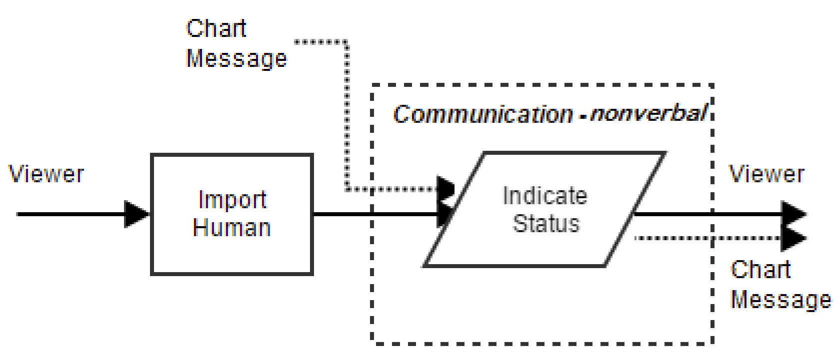
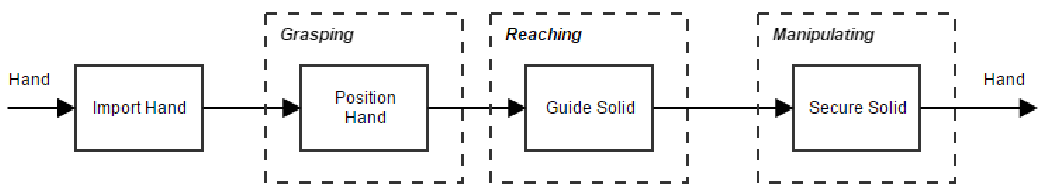


Figure 74. Actionfunction Diagram of Chart Modified by (Indicate Status, Seeing Functions) → (Parametric)

APPENDIX D: CASE STUDIES FOR RULE APPLICATIONS

Case 1: Fitted Bed Sheets

Users with diminished hand strength or dexterity, either due to age or injury, have trouble grasping products. Because they lack the necessary hand strength, users with impairments of the hand may not be able to maintain their grip on certain products as the user operates the product. In this case we consider the typical fitted bed sheet. In order to properly install the bed sheet, users must push and pull the sheet's edges around their mattress. Because fitted bed sheets contain elastic portions, it may be difficult for impaired users to pull the sheet after they have secured one or more corners. The actionfunction diagram for a typical bed sheet, along with related design rules, is shown in Figure 75. Clarkson's relevant design rule suggests a morphological change to the position hand functions, whereas Sangelkar's relevant rule suggests a parametric change to the same.



Rule Set	User Activity	Product Function	Recommended Change
Clarkson	Grasping	Position Hand	Morphological
Sangelkar	Grasping	Position Hand	Parametric

User Activity (ICF Term)	Meaning
Grasping	Using one or both hands to seize and hold something, such as when grasping a tool or a door knob.

Figure 75. Actionfunction Diagram and Rules for Case 1: Fitted Bed Sheets

Applying the relevant design guidelines yields the following two modified actionfunction diagrams. Clarkson's design rule leads to a morphological change to the 'Position Hand' function, suggesting a new physical solution to how a user would position their hands when grasping the sheets. The modified actionfunction diagram for applying Clarkson's rule of (Position Hand, Grasping) → (Morphological, Grasping) can be seen below in Figure 76. Sangelkar's similar design rule instead advises a parametric change to the 'Position Hand' function, suggesting a change to some parameter of the grip. The modified actionfunction diagram for applying Sangelkar's rule can be seen later in Figure 78.

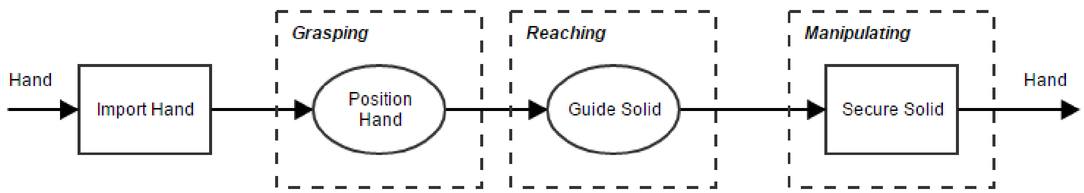


Figure 76. Bed Sheet Modified Using (Position Hand, Grasping) → (Morphological, Grasping)

Clarkson's design rule of (Position Hand, Grasping) → (Morphological, Grasping) suggests changing the physical solution of how a user grasps the sheets. For the purpose of this case study, we have chosen to develop a special gripping arm. A physical embodiment of this solution is sketched out in Figure 77. The gripping arm has a hook that grabs the sheets and allows the user to extend the grip arm to the proper location to secure the sheet. This grip arm is extendable, in order to allow users to reach the sheet without having to grip the sheets with their hands. A trigger assembly on the handle of the gripping arm allows users to disengage the hook and secure the sheet once it is in the proper location.

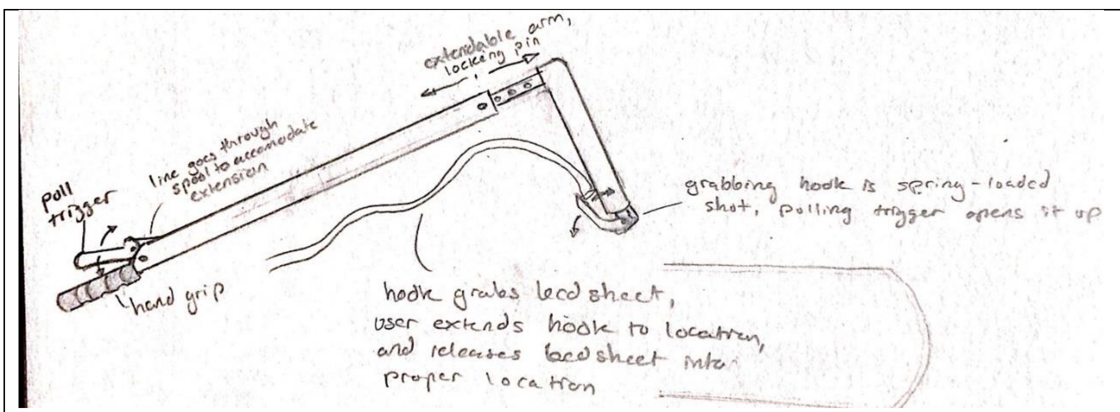


Figure 77. Representation of Bed Sheet Gripping Arm

Applying Sangelkar's design rule of (Position Hand, Grasping) → (Parametric, Grasping) yields the modified actionfunction diagram in Figure 78.

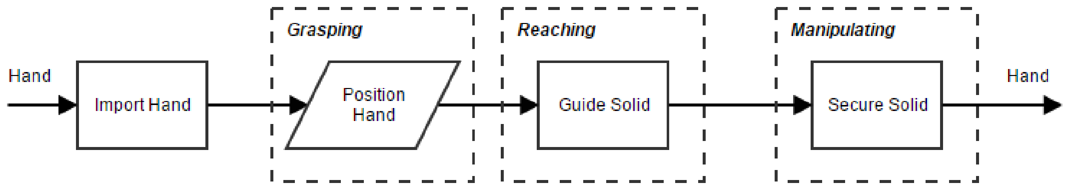


Figure 78. Cell Phone Modified Using (Position Hand, Grasping) → (Parametric, Grasping)

The parametric change recommended by Sangelkar's rule could suggests to designers that modifying the parameters of how the user grasps the sheet would lead to a more inclusive product. In order to provide more area for the user to grab ahold of, we have chosen to design in special handholds on the fitted sheet. These cloth handles would provide more room for the user to grip, and would be easier to securely grasp than the thin edges of a sheet. A physical embodiment of this proposed change is sketched out in Figure 79.

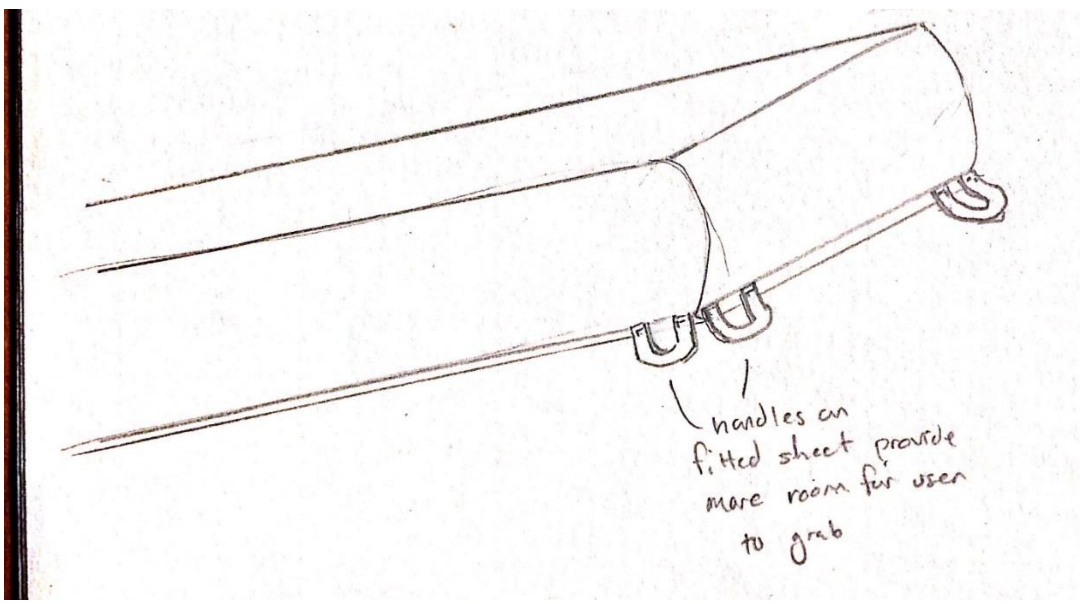
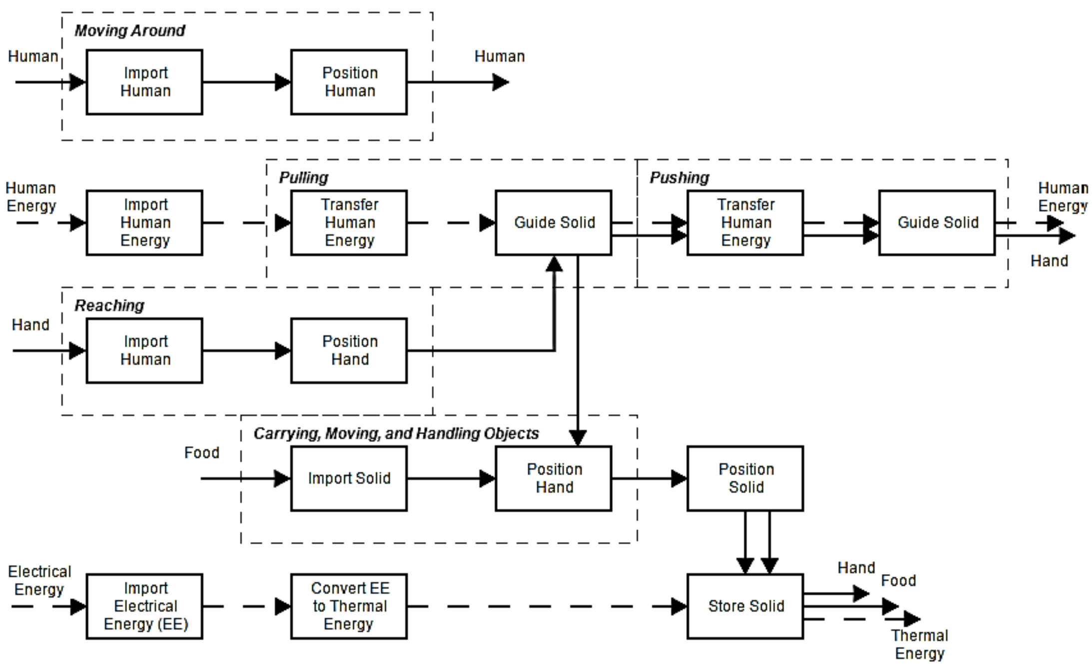


Figure 79. Representation of Fitted Sheet with Handles

Case 2: Refrigerator Door Latch

Consider the typical refrigerator. Users with diminished strength may find the force requirements too high for breaking the seal and opening the refrigerator door. Refrigerator door seals are generally tight due to magnetic strips as well as the pressure differential between the cool air inside and the warm air outside. While users may still be able to open the door through considerable application of their force, it could be beneficial for designers to develop a more easy to open refrigerator for persons suffering from arthritis, injuries, or other debilitating conditions. Clarkson's relevant design rule suggests a morphological change to how a user transfers force into the door. The actionfunction diagram for a refrigerator, along with a table of the relevant design rules, is provided in Figure 80.



Rule Set	User Activity	Product Function	Recommended Change
Clarkson	Carrying, Moving, and Handling Objects	Transfer Human Energy	Functional

User Activity (ICF Term)	Meaning
Carrying, Moving, and Handling Objects	Using the hands or arms to carry or move objects. Includes actions such as *Pulling*, *Pushing*, *Reaching*, and *Turning*

Figure 80. Actionfunction Diagram and Rules for Case 2: Refrigerator

Applying the relevant design guidelines yields the following modified actionfunction diagram. Clarkson's design rule leads to a functional addition in order to assist users in opening the refrigerator door. The modified actionfunction diagram for applying Clarkson's rule of (Transfer Human Energy; Carrying, Moving, and Handling Objects) → (Functional) can be seen below in Figure 81. In this case study, we have chosen to add in a 'Convert Human Energy (HE) to Mechanical Energy (ME)' function, with associated user activity of 'Manipulating', in order to assist a user in opening the refrigerator door. This functional addition is meant to represent the addition of features to create a mechanical advantage for the user so that they will able to open the door with less force.

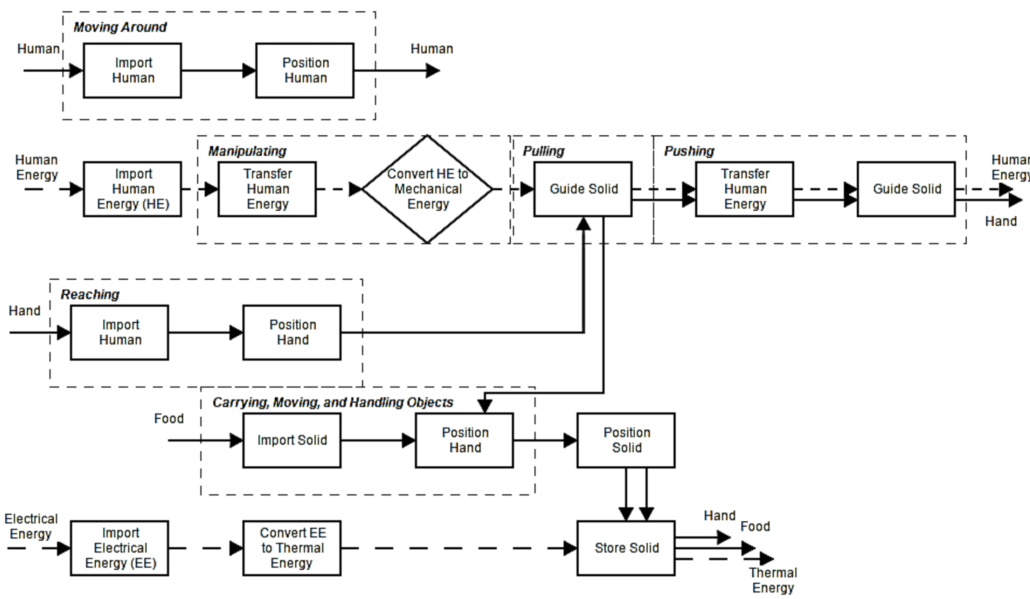


Figure 81. Refrigerator Modified Using (Transfer Human Energy; Carrying, Moving, and Handling Objects) → (Functional)

Clarkson's design rule of (Transfer Human Energy; Carrying, Moving, and Handling Objects) → (Functional) suggests adding in a function relating to the transfer of human energy in order to make a product more inclusive. When applied to the refrigerator, this rule lead to the addition of a 'Convert Human Energy to Mechanical Energy' function, which signifies some type of mechanical advantage that will make the refrigerator door easier to open. For the purpose of this case study, we have chosen to develop a special type of latch affixed to the refrigerator door that would eliminate the need for a tight seal and magnetic locks. A physical embodiment of this solution is sketched out in Figure 82. A latch would connect to a lever that is in turn connected to a seals in the door. When the latch is pulled, the lever is actuated and pulls the seals, thereby releasing the locks on the refrigerator door and allowing the door to freely swing open.

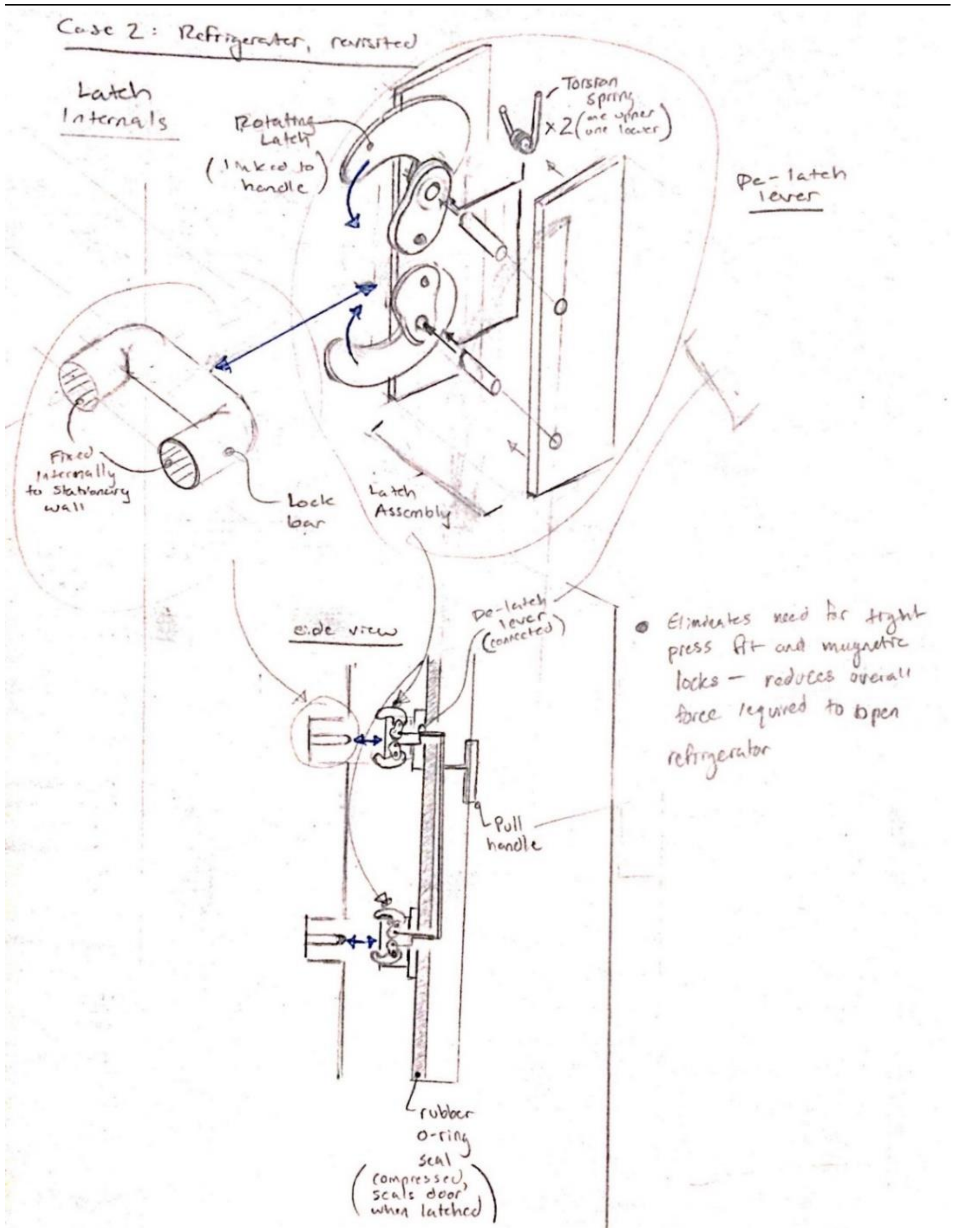
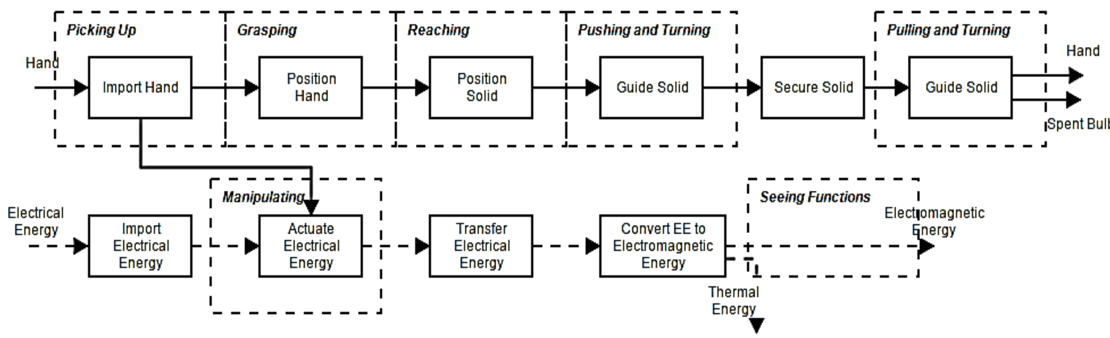


Figure 82. Representation of Refrigerator Latch Lock

Case 3: Light Bulb

Users with diminished hand strength may have difficulties performing activities that require simultaneous manipulations. One product that requires simultaneous manipulations is the child-proof pill bottle cap, which requires users to push and twist at the same time to disengage the cap. Many users have difficulty opening a pill bottle, which has led to many inclusive design alternatives, such as arthritis-friendly bottle caps. A lesser considered product that requires simultaneous manipulations is a lightbulb, as users must push and turn the lightbulb in order to install it. The actionfunction diagram for a light bulb and the correlating design rule is provided in Figure 83.



Rule Set	User Activity	Product Function	Recommended Change
Clarkson	Manipulating	Guide Solid	Morphological

User Activity (ICF Term)	Meaning
Manipulating	Using fingers and hands to exert control over, direct or guide something, such as when handling coins or other small objects. Can include *Pushing*, *Turning*, *Pulling* and other like activities.

Figure 83. Actionfunction Diagram and Rules for Case 3: Light Bulb

Applying the relevant design guidelines yields the following modified actionfunction diagram. Clarkson's design rule leads to a morphological change to alter the product so that simultaneous manipulations are not necessary. The modified actionfunction diagram for applying Clarkson's rule of (Guide Solid, Two Manipulating Functions) → (Morphological) can be seen below in Figure 84.

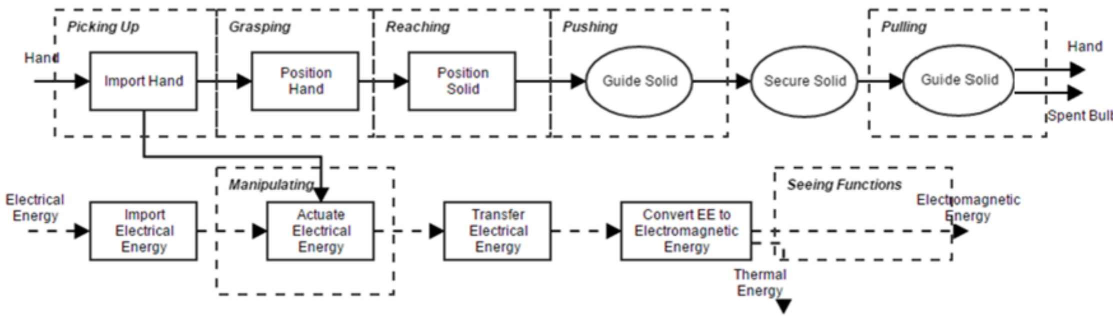


Figure 84. Light Bulb Modified Using (Guide Solid, Two Manipulating Functions) → (Morphological)

Clarkson's design rule of (Guide Solid, Two Manipulating Functions) → (Morphological) suggests changing the physical solution to the 'Guide Solid' function. When applied to the light bulb, this rule leads to a morphological change of how the light bulb is installed and uninstalled. Typical lightbulbs are installed by pushing and twisting the bulb into a threaded socket, which would be a difficult set of actions to perform for someone with some form of hand impairment. For the purpose of this case study, we have chosen to develop a new method of installing and uninstalling a light bulb. A physical embodiment of this solution is sketched out in Figure 85. This new method utilizes a special rotating latch mounted to a cage where the bulb sits. To install the light bulb, a user simply needs to push the bulb into the cage until it contacts the electrical contacts. The user continues pushing the bulb after the bulb contacts the electrical contact, thereby depressing the whole bulb-cage assembly. As the bulb-cage assembly is pushed down, it rotates two locking gears that are attached to two capture walls. When the bulb-cage assembly is fully depressed, these two capture walls fully enclose the base of the bulb, and the locking gears lock into position, thereby securing the whole assembly. This addition of a locking mechanism leads to the addition of a 'Secure Solid' function in the inclusive product function structure. To uninstall the bulb, a user needs to gently press the light bulb in, thus releasing the locking gears and the capture walls, after which the user can simply pull the bulb out of the socket.

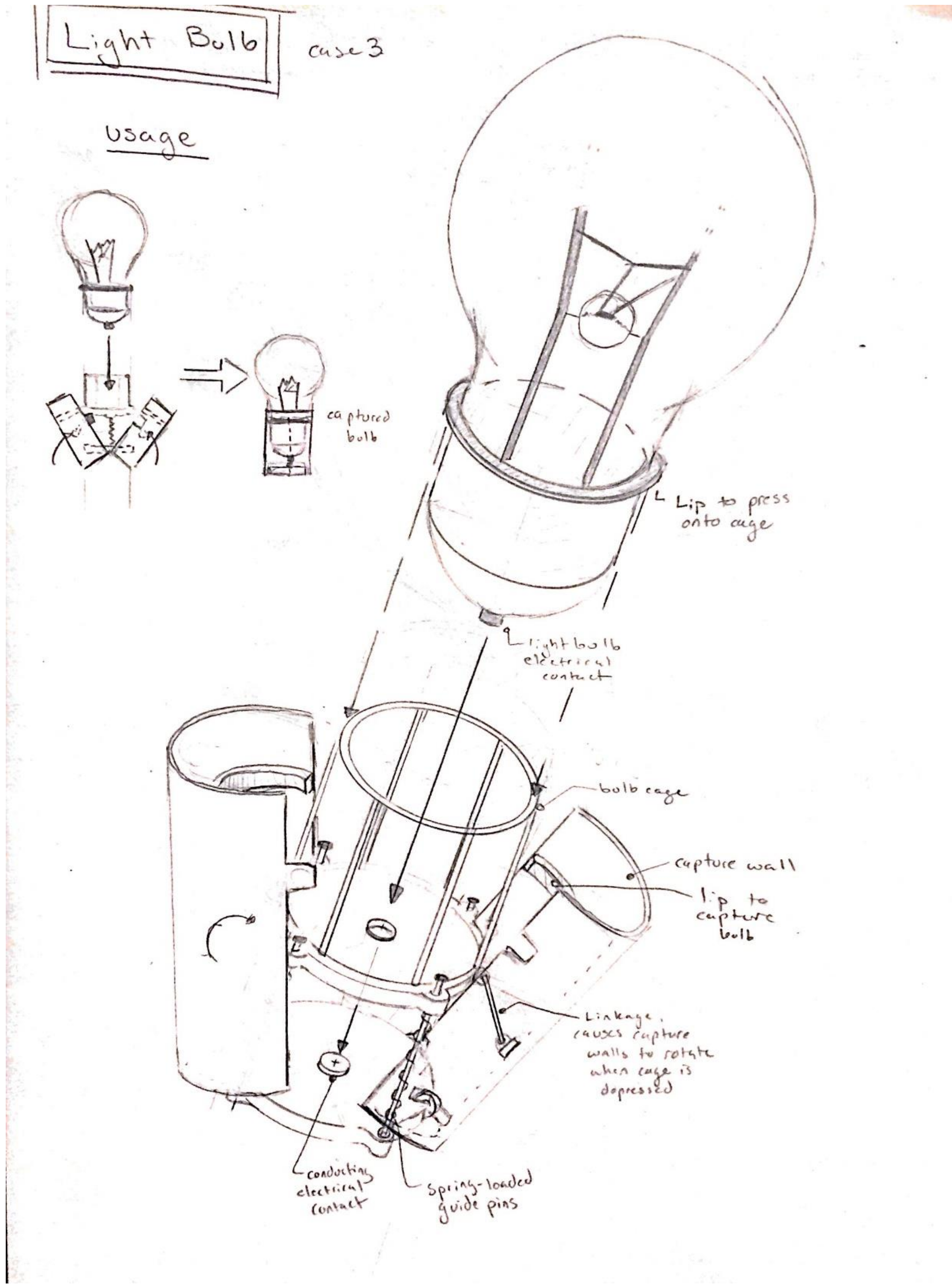
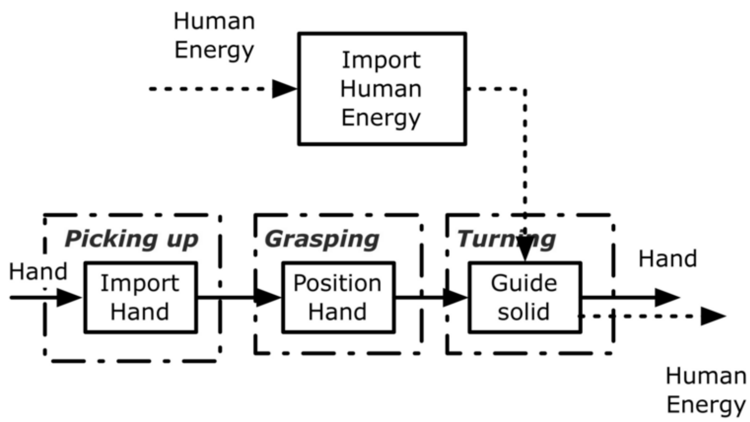


Figure 85. Representation of Light Bulb Modified Using (Guide Solid, Two Manipulating Functions) → (Morphological)

Case 4: Bottle Cap

Users with diminished dexterity may have difficulties utilizing a pincer grip to grasp objects, as is necessary when turning an object. Designers should consider modifying products that require turning to instead utilize a different user activity. A classic example of a product that requires gripping and turning is a twist-off bottle cap, such as one would find on a plastic water bottle. The actionfunction diagram for a plastic water bottle cap and the correlating design rule is provided in Figure 86.



Rule Set	User Activity	Product Function	Recommended Change
Clarkson	Turning	Guide Solid	Morphological

User Activity (ICF Term)	Meaning
Turning	Using fingers, hands and arms to rotate, turn or bend an object, such as is required to use tools or utensils.

Figure 86. Actionfunction Diagram and Rules for Case 4: Bottle Cap

Applying the relevant design guidelines yields the following modified actionfunction diagram. Clarkson's design rule leads to a morphological change to alter the product so that activities that originally required 'Turning' now require a different Manipulating function. . The modified actionfunction diagram for applying Clarkson's rule of (Guide Solid, Turning) → (Morphological) can be seen below in Figure 87.

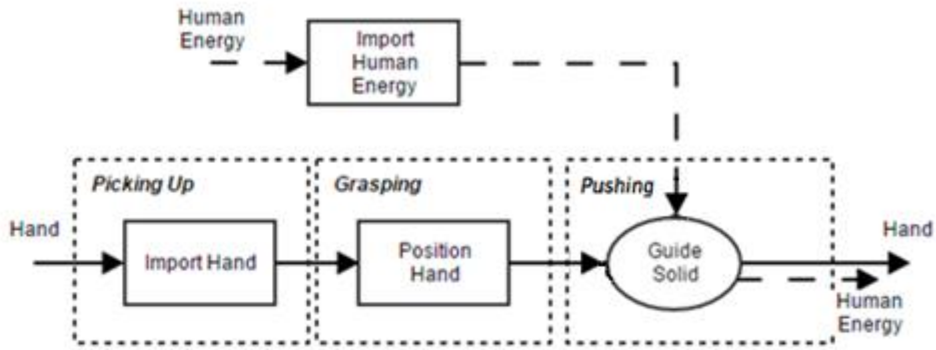


Figure 87. Bottle Cap Modified Using (Guide Solid, Turning) → (Morphological)

Clarkson's design rule of (Guide Solid, Turning) → (Morphological) suggests changing the physical solution to the 'Guide Solid' function. When applied to the bottle cap, this rule leads to a morphological change of how the bottle cap is attached to and removed from the bottle. Typical bottle caps are threaded onto a receiving thread on the bottle, a cheap and reusable way of sealing the bottle. In developing a more inclusive product, we must also consider the marketability of the resulting product. Current bottle caps are utilized due to their simplicity and low cost, so any new inclusive design should not unduly increase the cost or complexity of the system. A proposed solution to the actionfunction diagram of Figure 77 is pictured in Figure 88. This new design utilizes a detent feature on the inside of the bottle cap that fits into a groove in the mouth of the water bottle. To remove the bottle cap, the user pushes or pulls up on the bottle cap. Because the cap is made of a pliable plastic, the cap will elastically deform and thus clear the detent feature and release from the bottle. This detent feature, and the corresponding pushing and pulling manipulations, accounts for the morphological change to the 'Guide Solid' function. In order to avoid the bottle caps being accidentally deformed and opening the bottles, as may happen during the bumps and shocks involved in shipping, we have also added in a perforated plastic locking ring, which accounts for the 'Release Solid' functional addition. In order to release the bottle cap so that it may be opened, a user must first pull a tab on the locking ring and unravel it from the bottle cap. The newly modified bottle cap design can still be easily manufactured from the same materials and processes as the original twist-off bottle cap, and thus does not lead to a less marketable product.

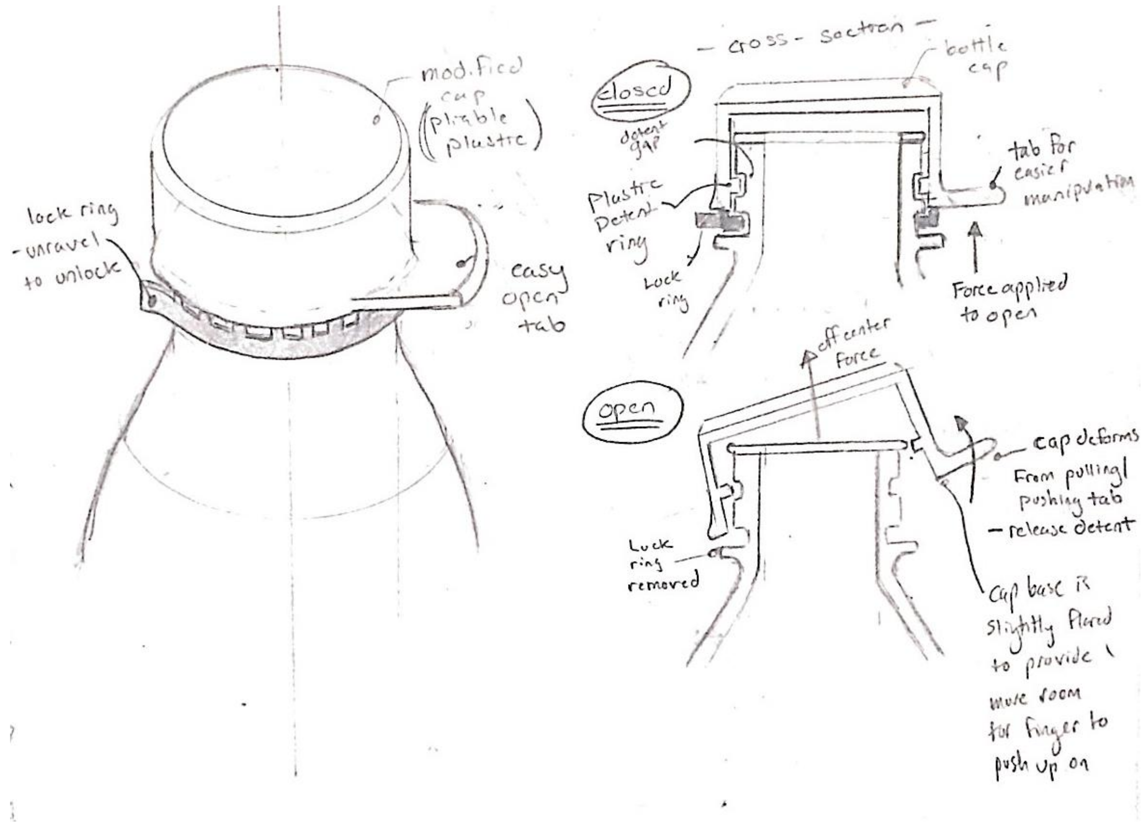
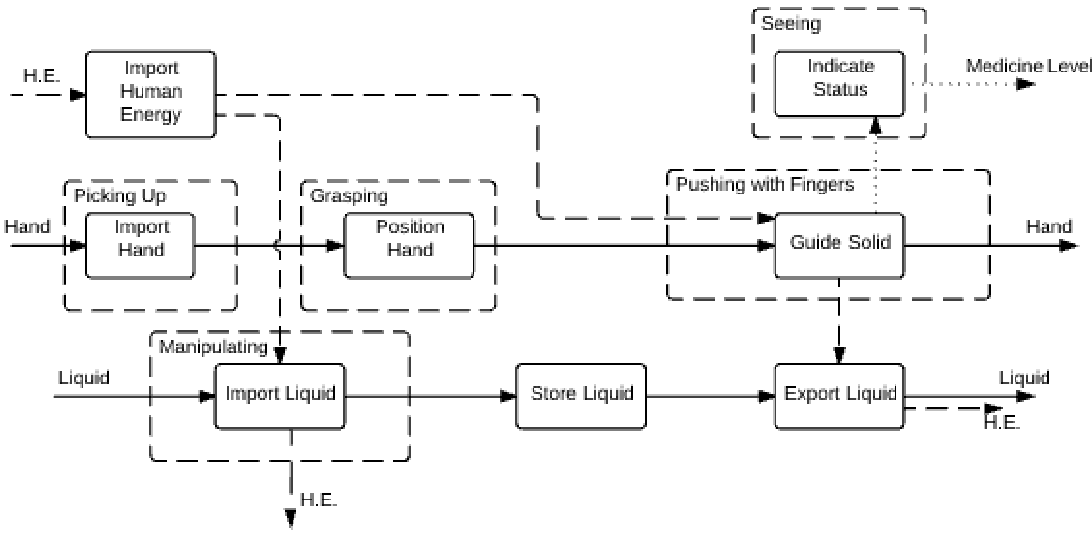


Figure 88. Representation of Bottle Cap Using (Guide Solid, Turning) → (Morphological)

Case 5: Grasping a Product

Users with diminished dexterity have difficulties firmly grasping products. Users may experience reduced dexterity due to a large number of factors including increased age, illnesses, or disabilities. One such product that could benefit from modification is a typical syringe, as its smooth and thin surface may prove difficult for disabled users to grasp. The actionfunction diagram and associated rule are pictured below.



Rule Set	User Activity	Product Function	Recommended Change
Clarkson AND Sangelkar	Grasping	Secure Hand	Functional

User Activity (ICF Term)	Meaning
Grasping	Using one or both hands to seize and hold something, such as when grasping a tool or a door knob.

Figure 89. Actionfunction Diagram and Rules for Case 5: Rubber Coatings

Users with reduced dexterity will have trouble firmly grasping products, such as the syringe, that are too thin, or that have smooth or slippery surfaces. Clarkson's relevant design rule proposes that designers should add functions to products that help to secure the user's hand. The resulting actionfunction diagram, developed by applying this relevant design rule, is shown in Figure 90.

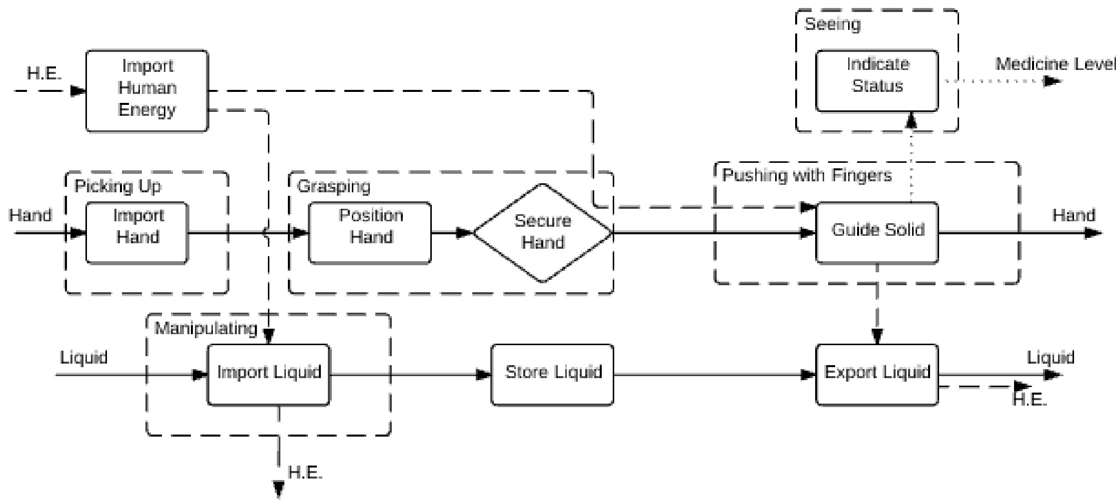
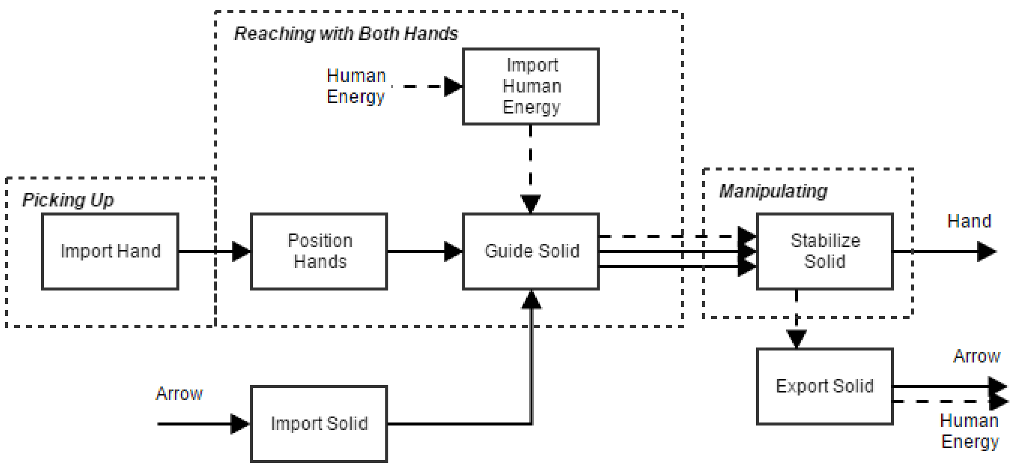


Figure 90. Syringe Actionfunction Diagram, Modified

One possible representation of the addition of this ‘Secure Hand’ function is coating the syringe tube with a rubber grip material. Coating these surfaces with a material that increases friction, such as a rubber grip, could allow users to more securely grip such products. This functional addition ensures that users will be able to more safely use the syringe, as the rubber material will aid users in grasping the syringe and holding it steady.

Case 6: Bow

In order to design more inclusive products, designers should allow for users to operate their products with a single hand, rather than two. Users who may be missing limbs or who have arm injuries would be unable to operate products requiring two hands or arms for operation. Consider a typical bow, for which the actionfunction diagram is pictured in Figure 91. A bow is not typically associated with disabled use, however archery is a sport many enjoy. Users with injuries, who previously enjoyed archery, would be unable to operate a bow normally without some modification. The corresponding design rule in this case deals with modifying the product such that user activities can be performed with a single arm rather than two.



Rule Set	User Activity	Product Function	Recommended Change
Clarkson	Reaching	Position Hand	Morphological

User Activity (ICF Term)	Meaning
Reaching	Using the hands and arms to extend outwards and touch and grasp something, such as when reaching across a table or desk for a book.

Figure 91. Actionfunction Diagram and Rules for Case 6: Bow

Applying the related design rule yields the actionfunction diagram of Figure 92.

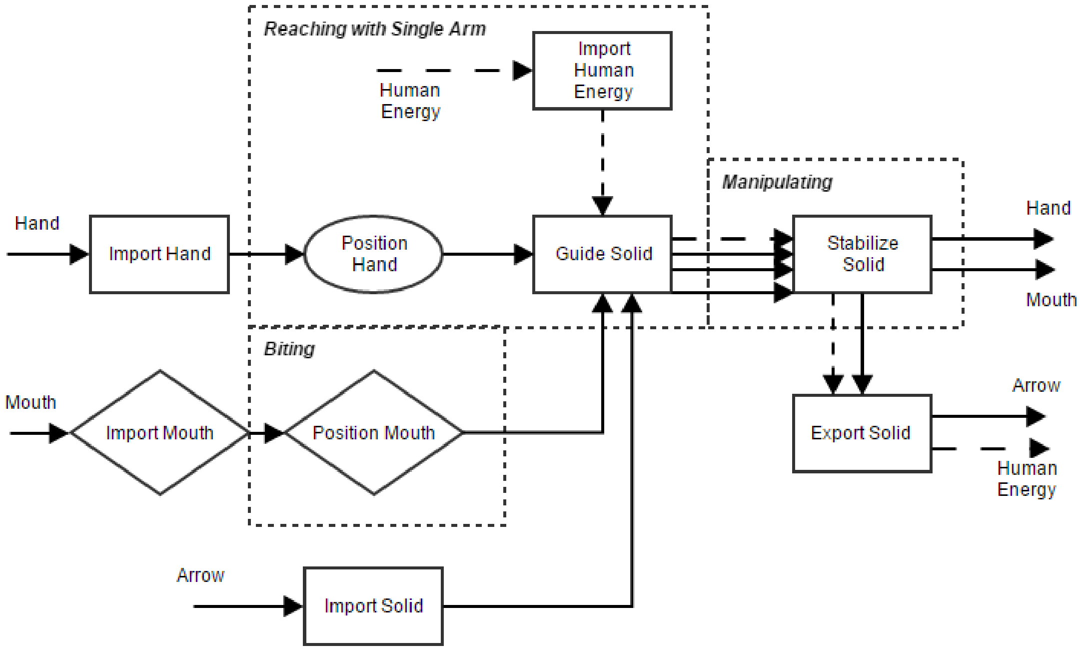


Figure 92. Bow Actionfunction Diagram Modified Using (Position Hand, Reaching) → (Morphological)

The relevant design rule suggest a morphological change to the bow in order to allow for operation to be accomplished using a single arm. For the purpose of this case, this is accomplished by adding in the functionality for the user to somehow hold the bow string (normally accomplished using the dominant hand) in their mouth. A physical representation of this modified actionfunction diagram is pictured in Figure 93. In this new design, a user would grasp the bow's handguard normally with one hand, while holding the bowstring using their mouth. A specially designed mouth grab allows the user to bite into a pliable rubber mouth guard attached to the bowstring. To draw the bow, the user would hold the bowstring (with a nocked arrow) using the mouth grab and extend the arm (holding the bow's handguard) forwards.

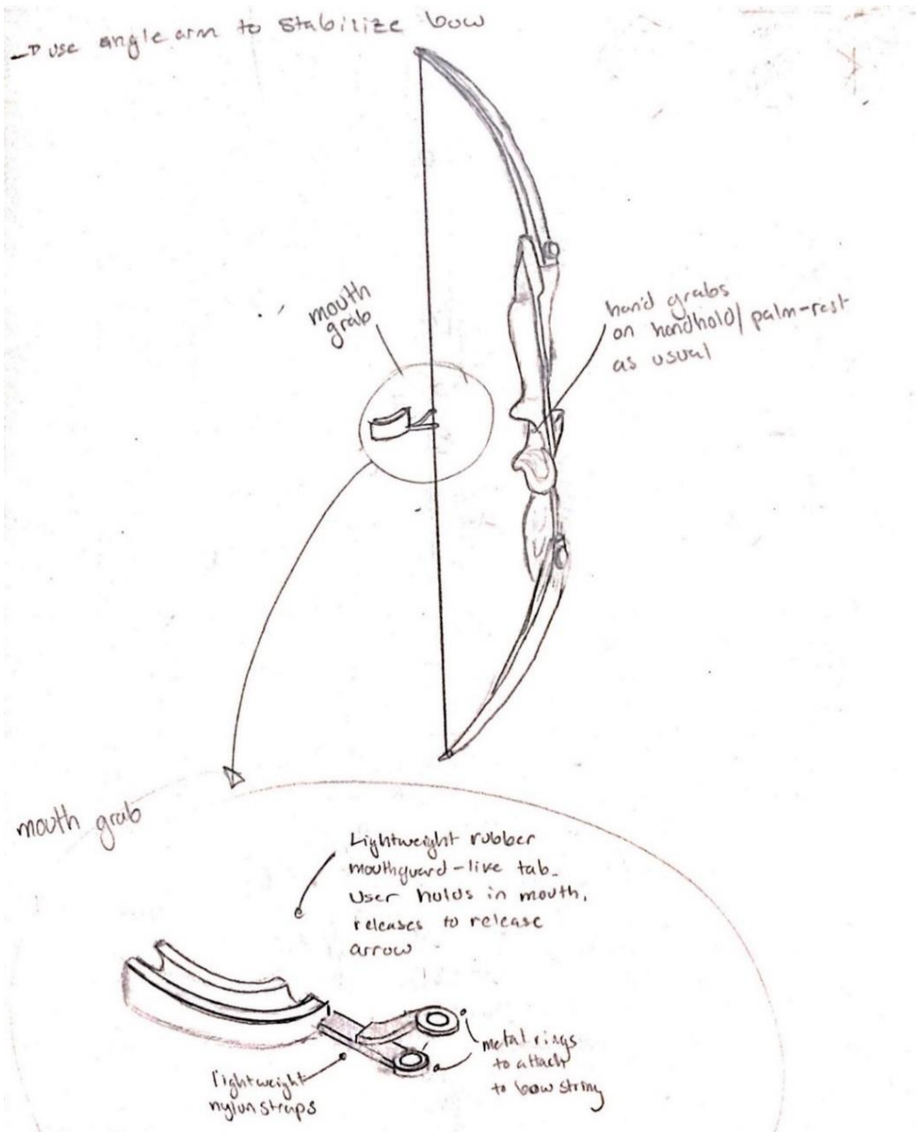
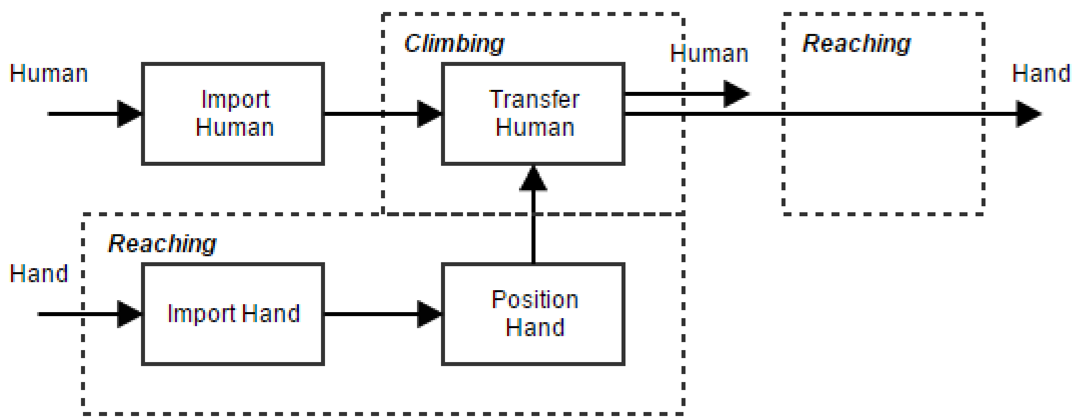


Figure 93. Representation of Modified Bow

It should be noted that, after some research, it was found that this design closely mimic bow tabs, which are used today by para-athletes and enthusiasts in the sport of archery. This is an interesting coincidence, that the changes suggested by the design rule leads to a very similar design as to one currently in use today for disabled athletes.

Case 7: Typical Ladder

Users with physical impairments have reduced reach when compared to able users. Consider the typical ladder, in which a less able user would have difficulty reaching their hands or arms to guide themselves up the ladder. The corresponding design rule in this case deals with modifying the product such that the user has to reach less of a distance while operating the product. The actionfunction diagram of a typical ladder, as well as the corresponding design rule, can be seen below in Figure 94.



Rule Set	User Activity	Product Function	Recommended Change
Clarkson	Reaching	Position Hand	Parametric

User Activity (ICF Term)	Meaning
Reaching	Using the hands and arms to extend outwards and touch and grasp something, such as when reaching across a table or desk for a book.

Figure 94. Actionfunction Diagram and Rules for Case 7: Ladder

Applying the related design rule yields the actionfunction diagram of Figure 95.

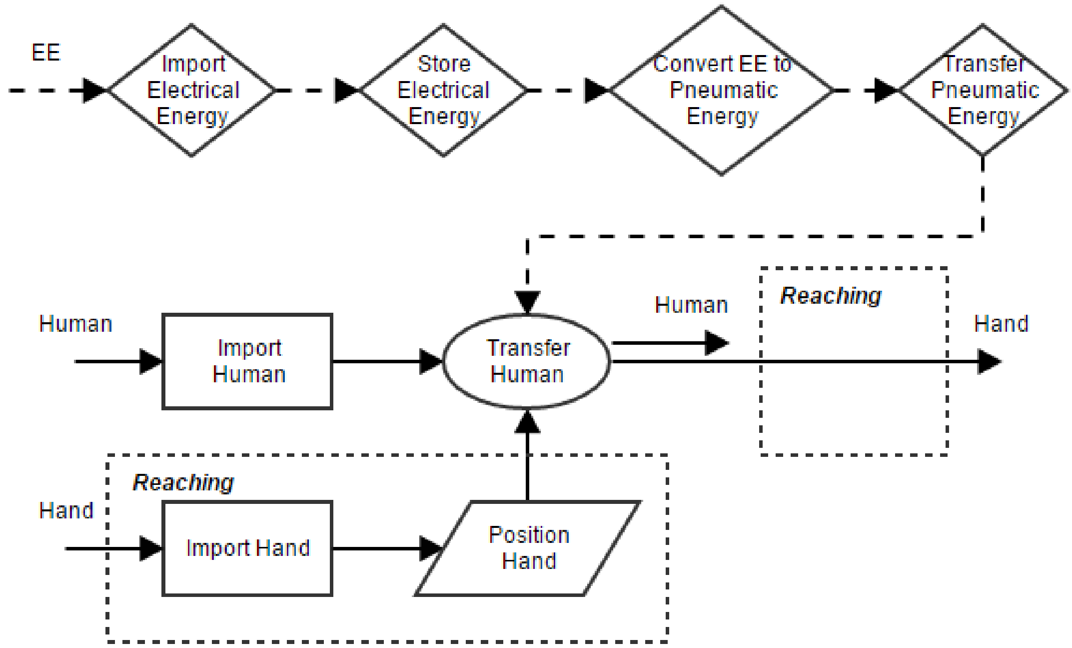


Figure 95. Ladder Actionfunction Diagram Modified Using (Position Hand, Reaching) → (Parametric)

The relevant design rule suggest a changes that modify the ladder to reduce the reach required to operate the ladder. In this case, we accomplish these changes by incorporating a hydraulic or pneumatic lift system. Now, instead of users having to reach for each ladder rung, they only have to reach for the first set of rungs. Once the user is on the first set of rungs, they can utilize the hydraulic or pneumatic pump to raise or lower the platform. A physical representation of this solution can be seen in the figure below. In the actionfunction diagram, we specifically reference a pneumatic system, however this design can be accomplished with either pneumatics or hydraulics.

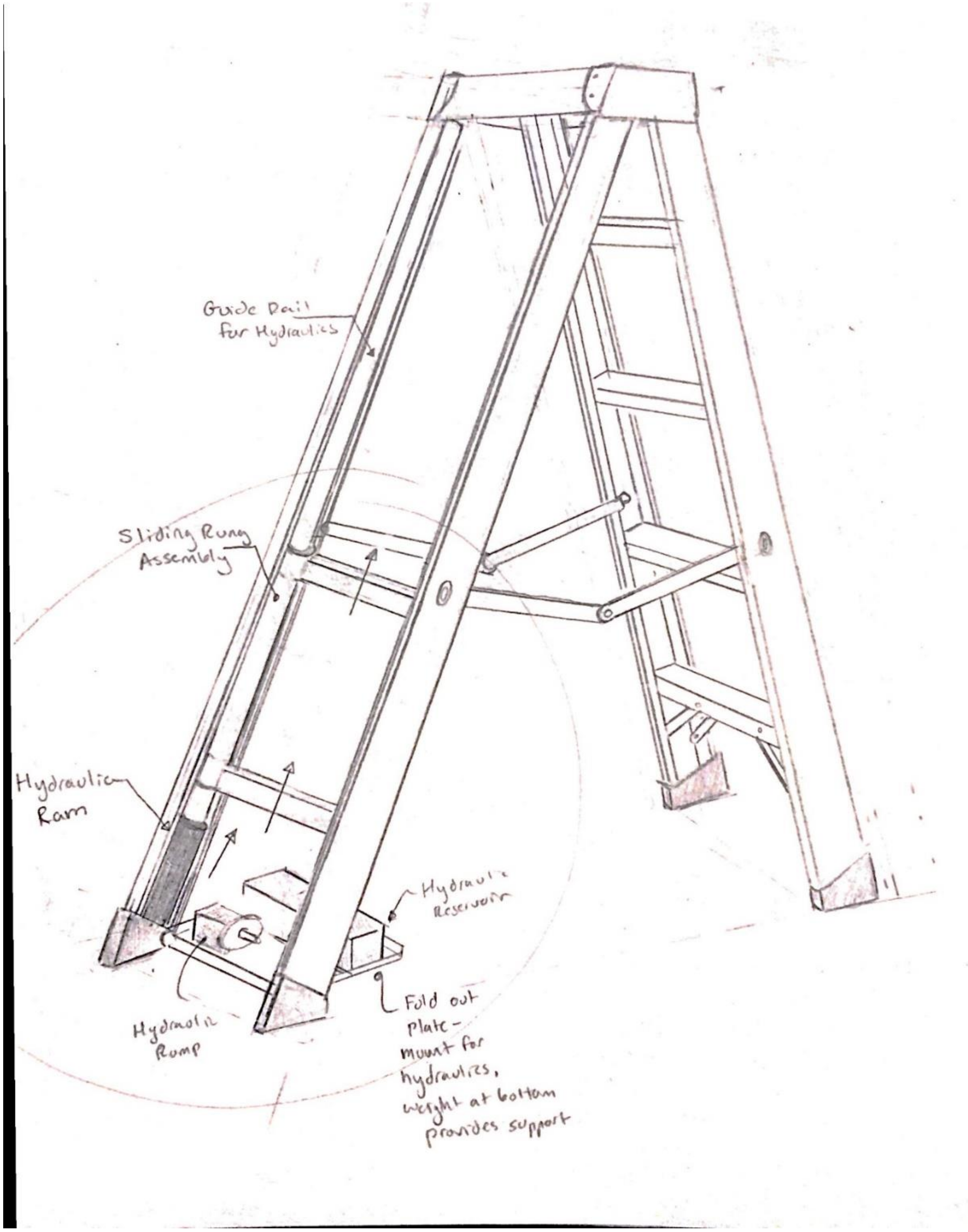
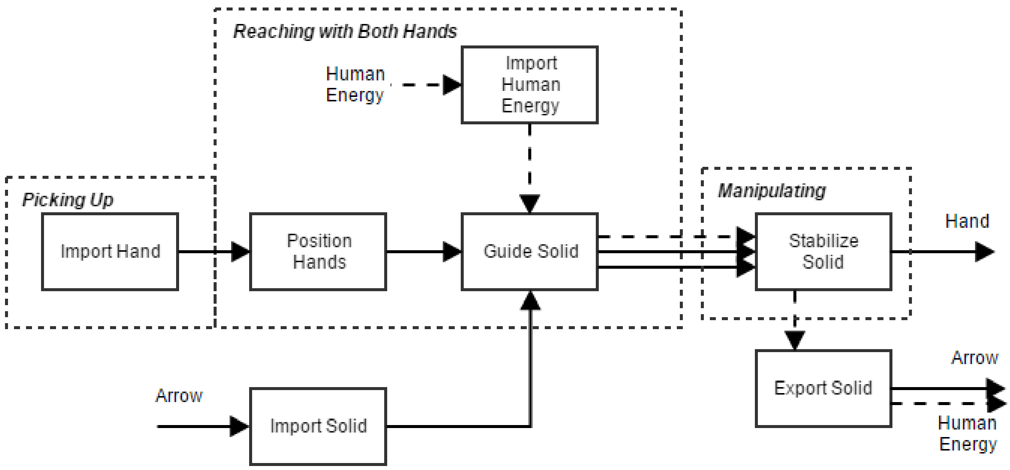


Figure 96. Representation of Modified Ladder

Case 8: Bow, Revisited

Users with physical impairments have difficulty exerting force with their arms outstretched. Consider the typical bow. While not typically associated with disabled users, archery is a sport many enjoy. Less able users would have difficulty drawing and steadying a typical bow, as they may not be strong enough to exert force with an outstretched arm. Designers should consider redesigning products such as a typical bow in such a way that users could operate the new products without exerting too much force with outstretched arms. The actionfunction diagram for a bow, as well as the corresponding design rule, are given below in Figure 97.



Rule Set	User Activity	Guide Solid	Recommended Change
Clarkson	Reaching	Guide Solid	Morphological

Figure 97. Actionfunction Diagram and Rule for Case 8: Bow

Applying Clarkson's design rule in this case yields a morphological change to the 'Guide Solid' function under the 'Reaching with Both Hands' user activity. This results in a change to how a user physically holds the bow and draws the bowstring back. In this case, we have accomplished these modifications by adding in a foot mount. The modified actionfunction diagram is shown in **Error! Reference source not found.**Figure .

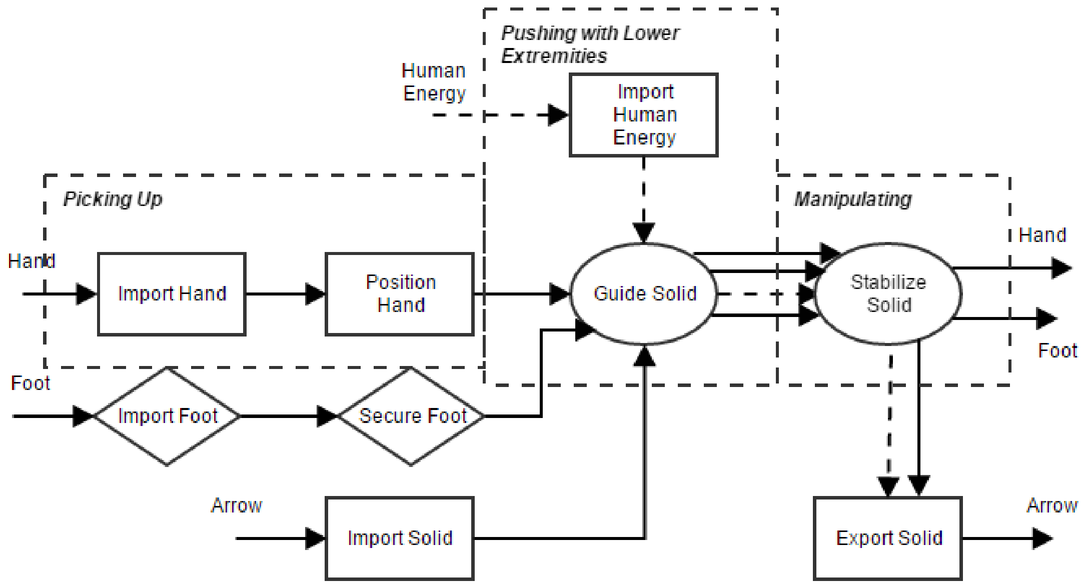


Figure 98. Modified Actionfunction of Case 8: Bow

Applying Clarkson's design rule in this results in a change to how a user physically holds the bow and draws the bowstring back. In this case, we have accomplished these modifications by adding in a foot mount, as can be seen in Figure 99 and Figure 100. To operate this bow, a user will secure their foot inside the toe clips attached to the foot stabilizer. This stabilizer is mounted to the bow by way of adjustable bolts. Once their foot is mounted, the user will then nock an arrow on the bowstring and securely hold the arrow in their operating hand. To draw the bowstring, the user then extends their leg to push the bow forwards, while holding their arm in the same spot. Release of the arrow is the same as a typical bow, with the user simply releasing their grasp on the arrow. This new design eliminates the need for the user to exert force with an outstretched arm and leads to a more inclusive product.

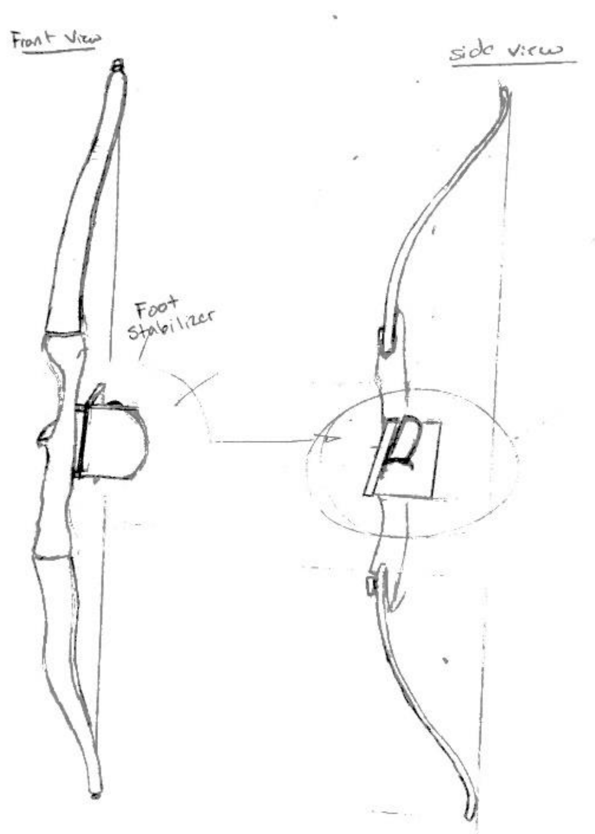


Figure 99. Overview of Modified Bow from Case 8

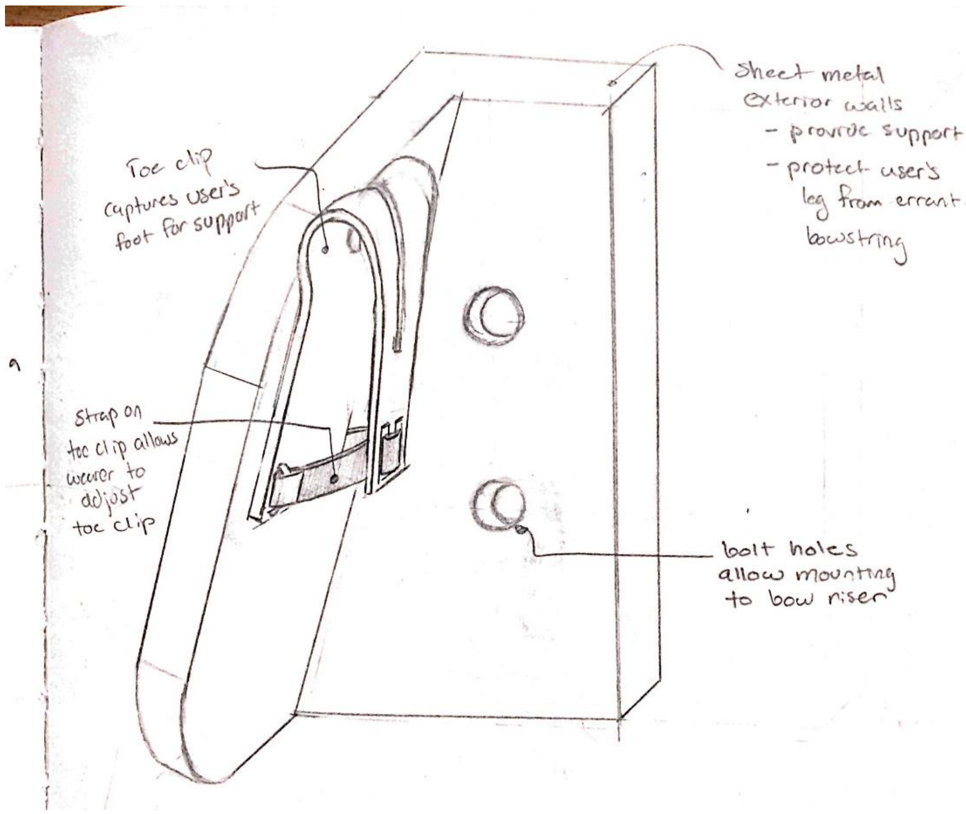
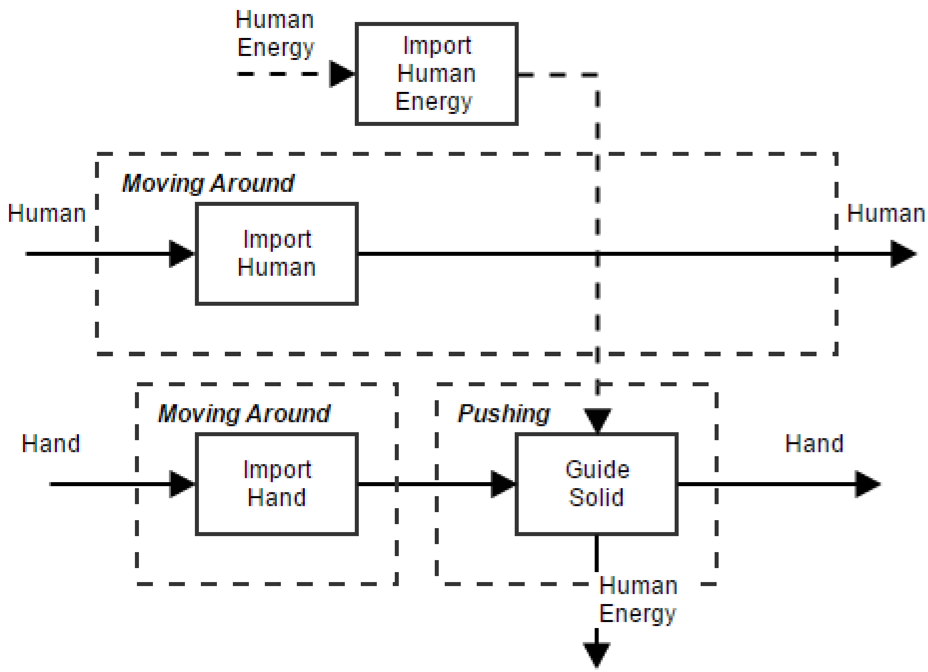


Figure 100. Modified Bow Foot Stabilizer from Case 8

Case 9: Entry and Exit

In order to make products and environments more inclusive, designers should set entry and exit dimensions large enough to provide adequate space for all potential users. Designers should consider users' locomotive aids, such as walkers and wheelchairs, when setting these dimensions so as to not exclude any potential users. The actionfunction diagram for one such product, a typical door, is pictured below with the relevant design rule.



Rule Set	User Activity	Product Function	Recommended Change
Clarkson	Moving Around	Import Human	Parametric

User Activity (ICF Term)	Meaning
Moving Around	Moving the whole body from one place to another

Figure 101. Actionfunction Diagram and Rule for Door in Case 9: Entry and Exit

Applying Clarkson's design rule here results in a parametric change to the 'Import Human' function pertaining to a user walking through the door. These parametric changes could include changes to the height or width of the door entryway. Increasing the doorway dimensions would lead to a more inclusive product, and would allow access users of all dimensions (be they physically impaired or not). The modified actionfunction is pictured below in Figure 102.

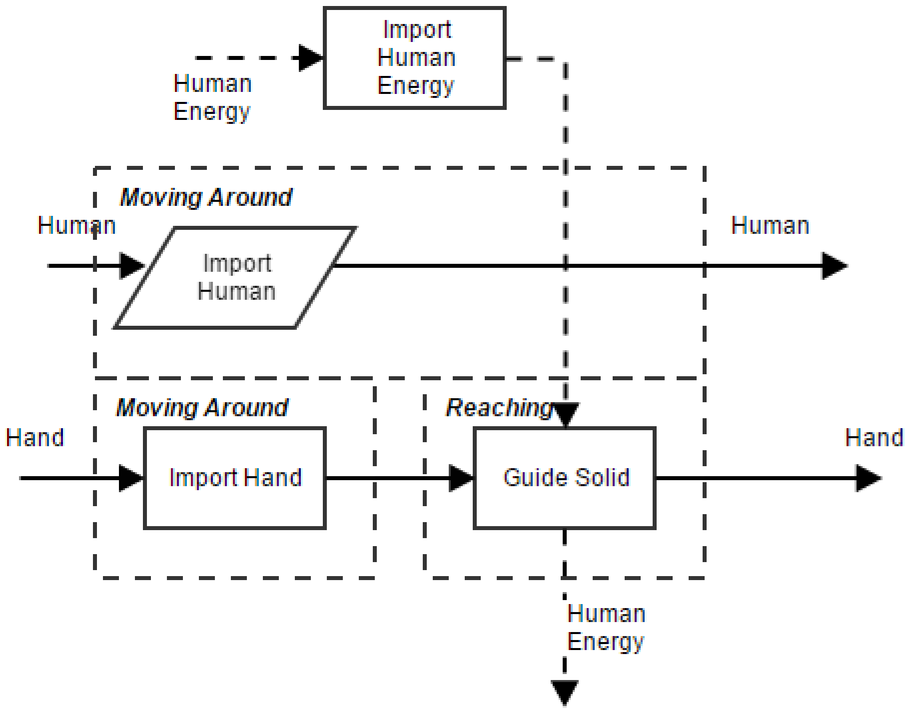
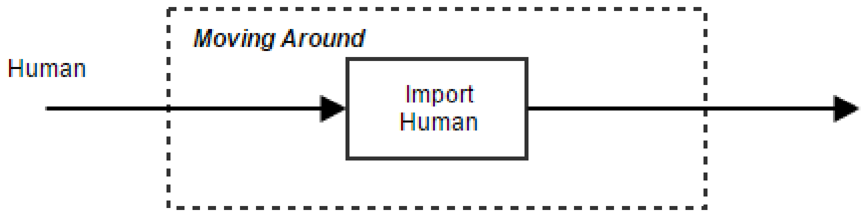


Figure 102. Modified Actionfunction Diagram for Door in Case 9: Entry and Exit

Case 10: Supports

In order to design more inclusive environments and to assist less abled users, designers should consider providing adequate seating and resting areas at regular intervals. Physically impaired users may have difficulty moving through an environment without rest, and may require seating areas to support themselves as they move through the environment. A basic actionfunction diagram of an environment a user would walk through is provided in Figure 103, as well as a relevant design rule.



Rule Set	User Activity	Product Function	Recommended Change
Clarkson	Moving Around	Support Human	Functional addition

User Activity (ICF Term)	Meaning
Moving Around	Moving the whole body from one place to another

Figure 103. Actionfunction Diagram and Rule for Case 10: Supports

Applying Clarkson's relevant design rule here results in the functional addition of a 'Support Human' function, signifying to the designer that adding in the functionality of supporting a user would lead to a more inclusive environment. The modified actionfunction diagram is shown in Figure 94.

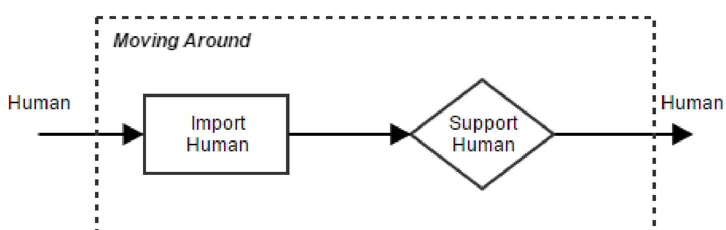
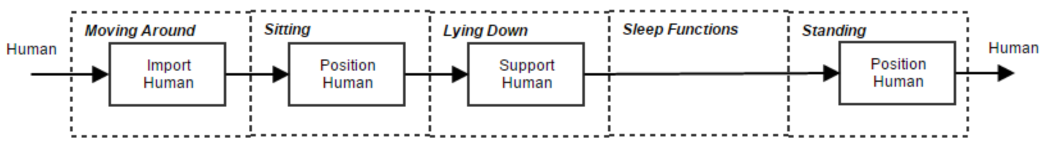


Figure 104. Modified Actionfunction Diagram for Case 10: Supports

Case 11: Bed

Users with lower body disabilities have difficulty standing and sitting unsupported. Designers should take this into consideration when designing products that requires users to sit on or stand up from. The actionfunction diagram related to a user sitting on and standing up from a typical bed is provided below in Figure 105.



Rule Set	User Activity	Product Function	Recommended Change
Clarkson	Changing Basic Body Positon	Support Human	Functional addition
Sangelkar	Sitting or Standing	Guide Human	Functional Addition

User Activity (ICF Term)	Meaning
Changing Basic Body Position	Getting into and out of a body position and moving from one location to another
Sitting	Getting into and out of a seated position and changing body position from sitting down to any other position, such as standing up or lying down.
Standing	Getting into and out of a standing position or changing body position from standing to any other position, such as lying down or sitting down.

Figure 105. Actionfunction Diagram and Rules for Case 11: Bed

Applying Clarkson's rule in this case results in the functional addition of a 'Support Human' function under both the 'Sitting' and 'Standing' user activities. These additions suggest to designers that, in order to develop a more inclusive product, components must be added that support users while they are sitting and standing using the bed. These functional additions can be accomplished by adding in a rotating grab bar that locks into position and provides users support as they change body positions. The actionfunction diagram for the bed, modified by Clarkson's design rule, can be seen in Figure 106.

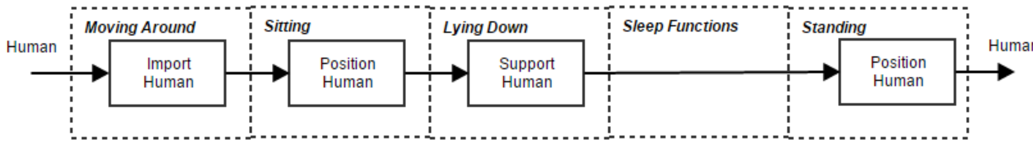


Figure 106. Bed Actionfunction Modified by Clarkson's Rule

The functional additions suggested by Clarkson's rule in this case can be accomplished by adding in rotating grab bars. These bars will be stored in the bed frame and will remain out of sight when not in use. When the user requires support, they can pull the grab bar up into the locked position and then utilize the grab bar as support. This grab bar also serves an added function by providing a pseudo-wall that can ensure the user does not roll out of bed when sleeping. The bed modified by Clarkson's design rule can be seen in Figure 107.

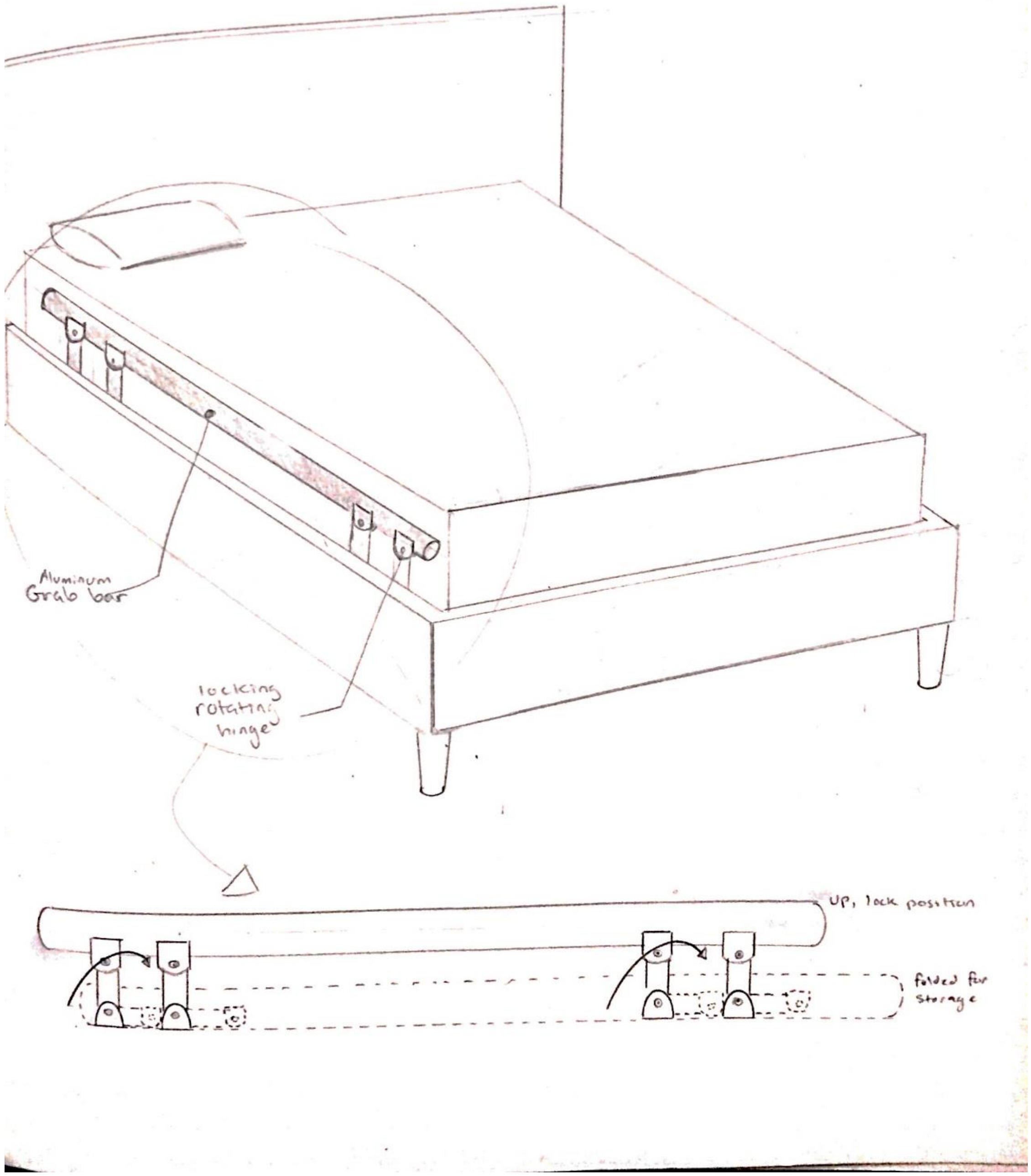


Figure 107. Representation of Bed Modified by Clarkson's Rule

Applying Sangelkar's rule in this case results in the functional addition of a 'Guide Human' function under both the 'Sitting' and 'Standing' user activities. These additions suggest to designers that, in order to develop a more inclusive product, components must be added that guide users into a sitting or standing position. These functional additions can be accomplished by adding in a hydraulic lifting seat system. The actionfunction diagram for the bed, modified by Sangelkar's design rule, can be seen in Figure 108.

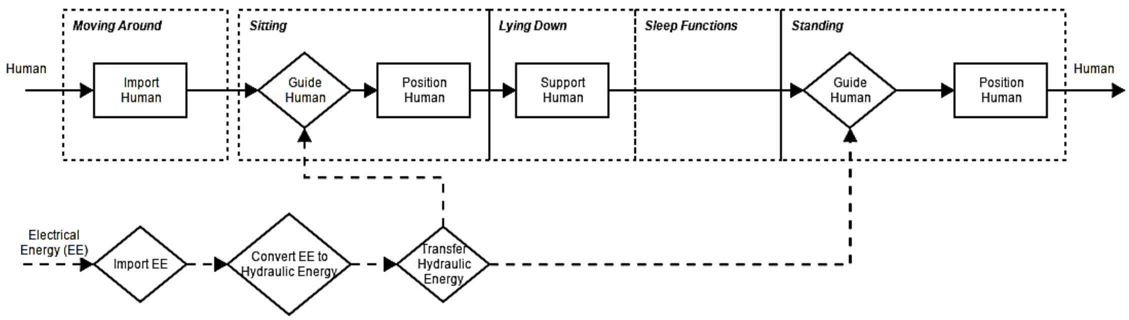


Figure 108. Bed Actionfunction Modified by Sangelkar's Rule

The functional additions suggested by Sangelkar's rule in this case can be accomplished by adding in a hydraulic lifting system. This lifting system is comprised of a rolling base with a large hand rail for support. The hydraulics are mounted to this rolling base, and are attached to a cushioned seat. The hydraulics and seat are guided by guide rods, and are actuated by a user-controlled panel. To sit on the bed, a user first approaches the hydraulic seat and sits on the seat at the highest position. By actuating the seat down, the user receives aid in sitting on the bed. Conversely, when wishing to stand up from the bed, a user would position themselves on the lifting seat and use the hydraulics to aid themselves in standing. The modified hydraulic lifting seat is pictured in Figure 109 and Figure 110.

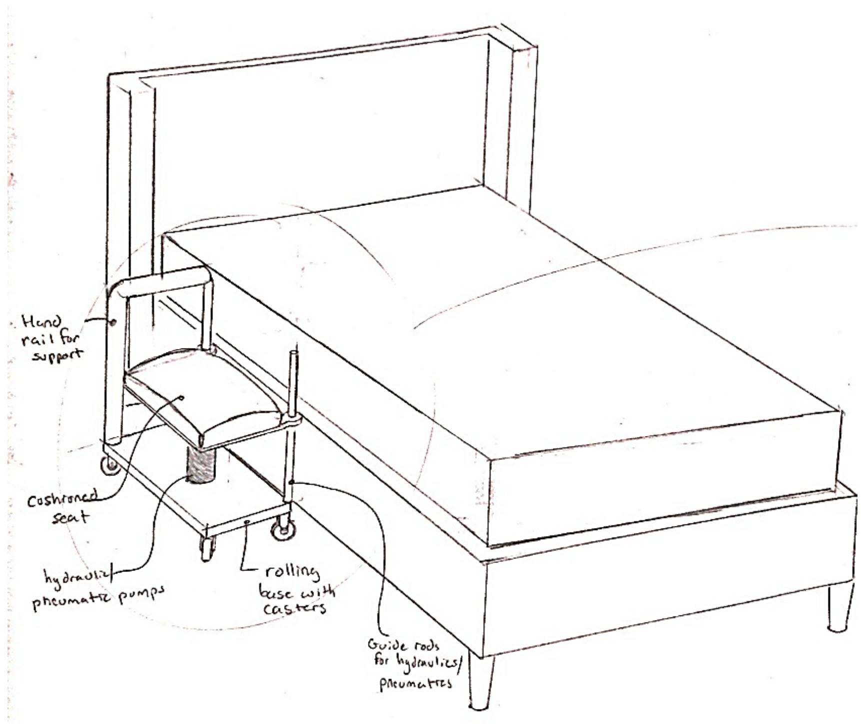


Figure 109. Overview of Bed Modified by Sangelkar's Rule

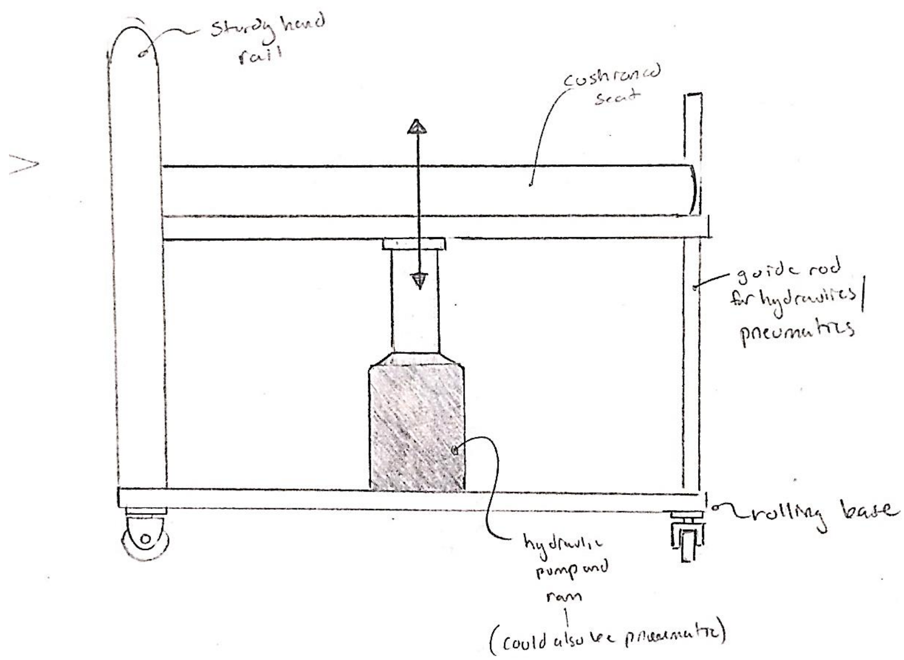
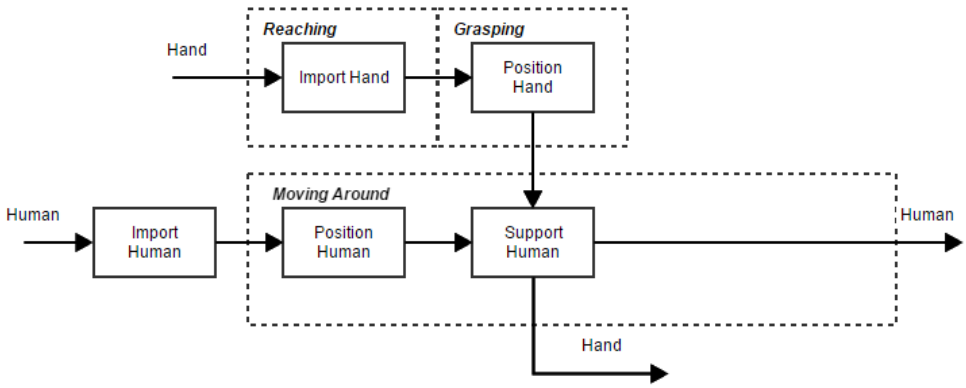


Figure 110. Hydraulic Lift from Sangelkar's Rule

Case 12: Grab Bars

Grab bars and rails have the potential to be very obstructive and aesthetically displeasing. In order to avoid making products and environments look too ‘assistive’ or ‘medical’, designers should incorporate supports into the overall aesthetic of the design. By making products more aesthetically pleasing, designers can help remove some of the stigma of owning more accessible devices. The actionfunction diagram for a typical set of grab bars or hand rails can be seen below in Figure 111.



Rule Set	User Activity	Product Function	Recommended Change
Clarkson	Moving Around	Support Human	Morphological

User Activity (ICF Term)	Meaning
Moving Around	Moving the whole body from one place to another

Figure 111. Actionfunction Diagram and Rule for Case 12: Grab Bars

Applying Clarkson’s design rule in this case leads to morphological changes to how the grab bar functions. By physically altering how the grab bar functions, designers can modify the product so that the rails no longer stick out as obstructive. By developing a more aesthetically pleasing product, designers can remove the stigma of owning ‘assistive’ products, which could lead to more widespread use of the inclusive products. The modified actionfunction diagram from this design rule can be seen in Figure 112.

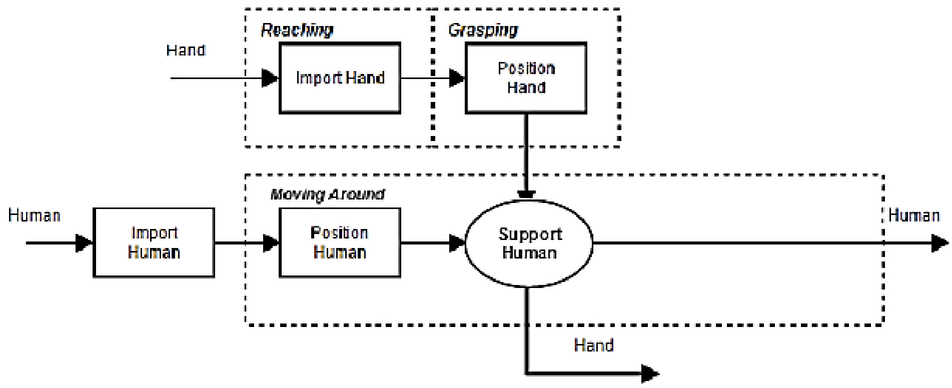


Figure 112. Modified Actionfunction Diagram for Case 12: Grab Bars

Consider the typical grab bars on a bath tub. Typically grab bars on bath tubs are seen as ‘assistive’ products, and could turn away some users. By instead utilizing a set of rotating grab bars, designers can ensure that the grab bars do not get in the way of normal operation of the bath tub. A representation of this solution can be seen below in Figure 113.

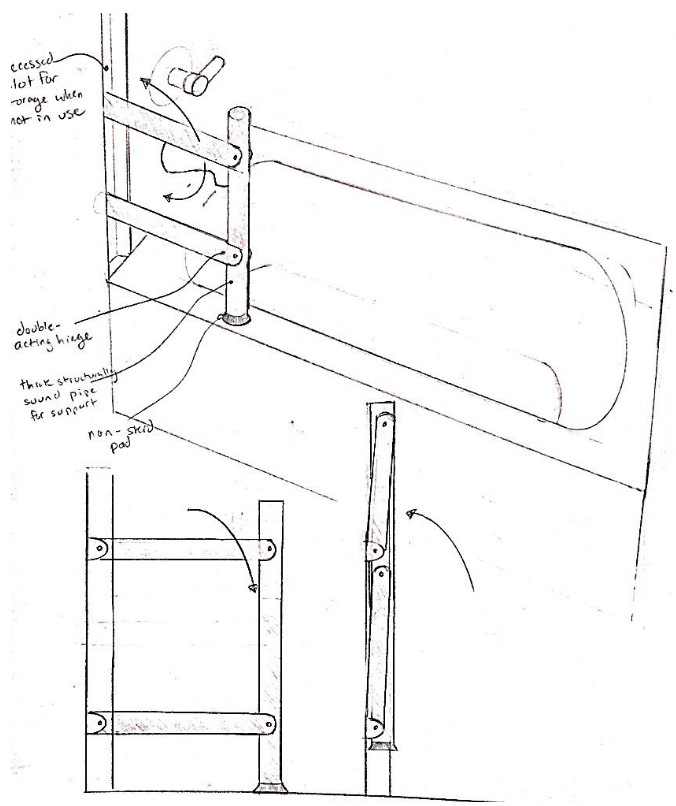
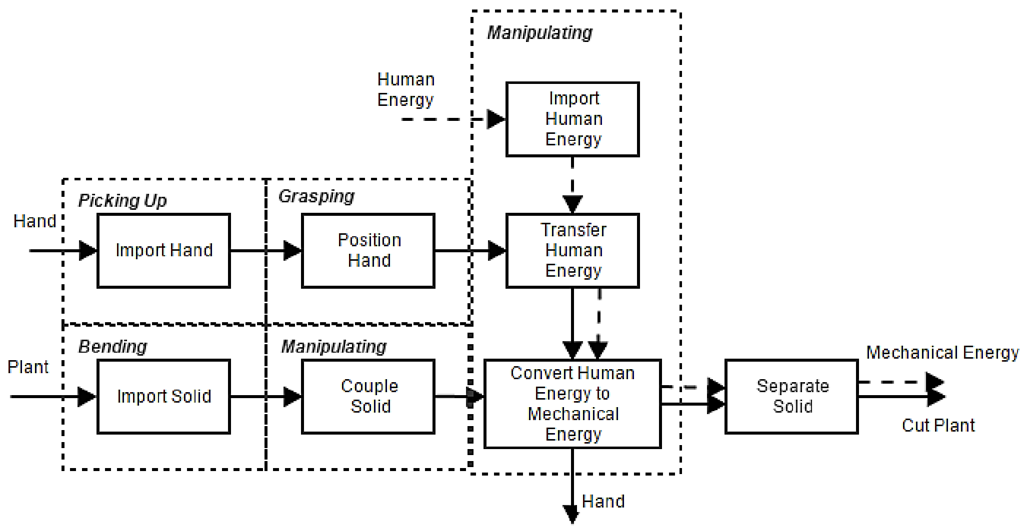


Figure 113. Modified Bath Tub Grab Bars

Case 13: Garden Shears

Users with limited lower body ability or back trouble have trouble bending at the waist. In order to develop more inclusive designs, designers should consider removing the need to bend over to utilize the product. A typical product that requires users to bend over during is a set of garden shears, which require the user to bend over to couple the shears with low-lying vegetation. The actionfunction diagram of a set of typical garden shears is pictured below, as well as an applicable design rule.



Rule Set	User Activity	Product Function	Recommended Change
Clarkson	Bending	Interfacing with Product	Morphological

User Activity (ICF Term)	Meaning
Bending	Tilting the back downwards or to the side, at the torso, such as in bowing or reaching down for an object.

Figure 114. Actionfunction Diagram and Rule for Case 13: Garden Shears

The relevant design rule suggests a morphological change to the functions under the user activity of 'Bending' in order to develop a more inclusive product. In this case, applying the relevant design rule yields a morphological change to the 'Import Solid' function, which relates to how a user brings the garden shears in contact with a plant or other object to be cut. The modified actionfunction diagram is pictured in Figure 115.

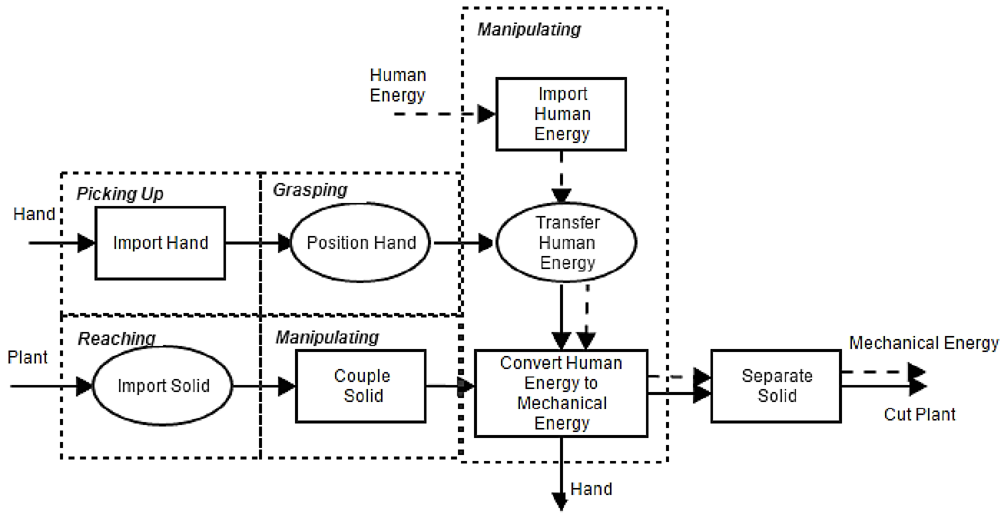


Figure 115. Modified Garden Shears Actionfunction Diagram

The relevant design rule suggests a change to the physical method that a user brings the garden shears in contact with a plant or other object so that a user does not have to bend over in order to use the product. In this case, we have chosen to modify the garden shears so that a user can instead accomplish the 'Import Solid' function through the user activity of 'Reaching'. A sketch of the newly modified garden shears is shown in Figure 116. For the purpose of this case, we have modified the overall length of the garden shears by incorporating an adjustable length handle. This handle allows the user to adjust the length of the shears as desired, while a lockable rotating blade head allows the user to adjust the angle of the blades in order to account for all angles of use. The new garden shears' blades are actuated by the user pulling a trigger on the handle, which in turn pulls on a cable inside the handle that attaches to the blades. This new handle and trigger assembly modify how a user positions their hand while grasping the product, thus represented by a morphological change to the 'Position Hand' function under the user activity of 'Grasping'. The cable that actuates the garden shear blades entails a new physical method of transferring human energy to move the blades, thus resulting in the morphological change to the 'Transfer Human Energy' function. In order to account for the adjustable length of the garden shears, the cable is wound around a spring-loaded reel that ensures the cable length is always compatible with the handle length. This new design for garden shears, suggested by a relevant inclusive design rule, will allow users to utilize the shears on low-lying plants without having to bend over.

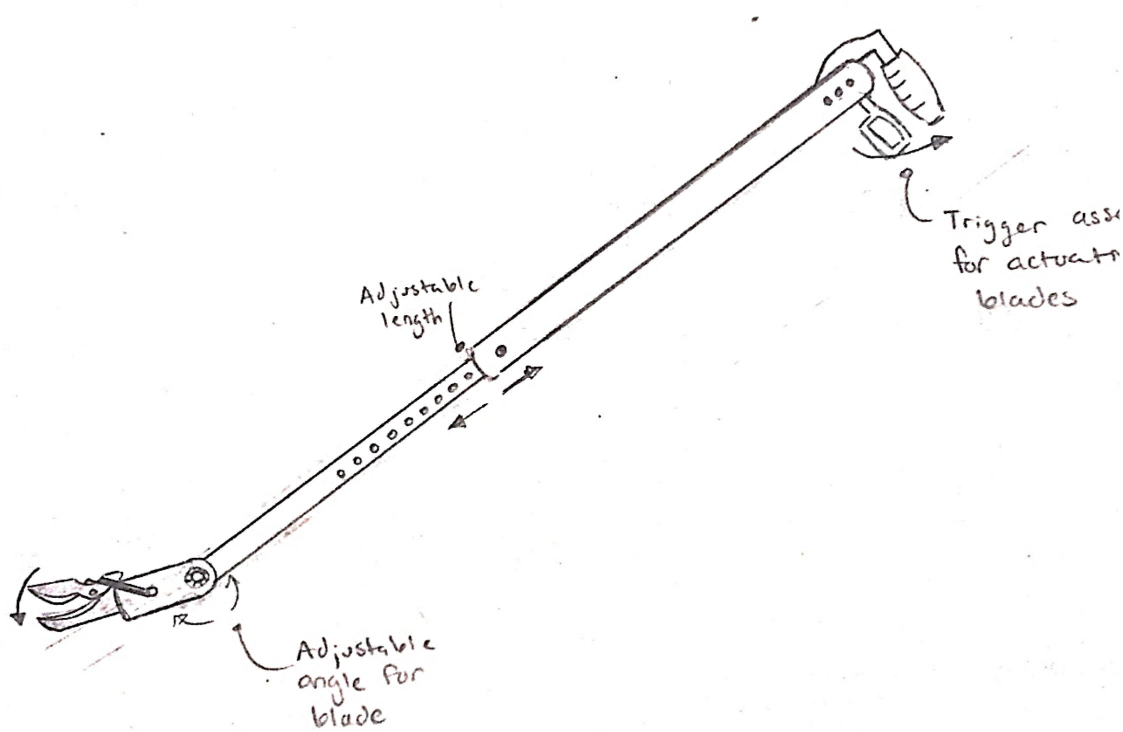
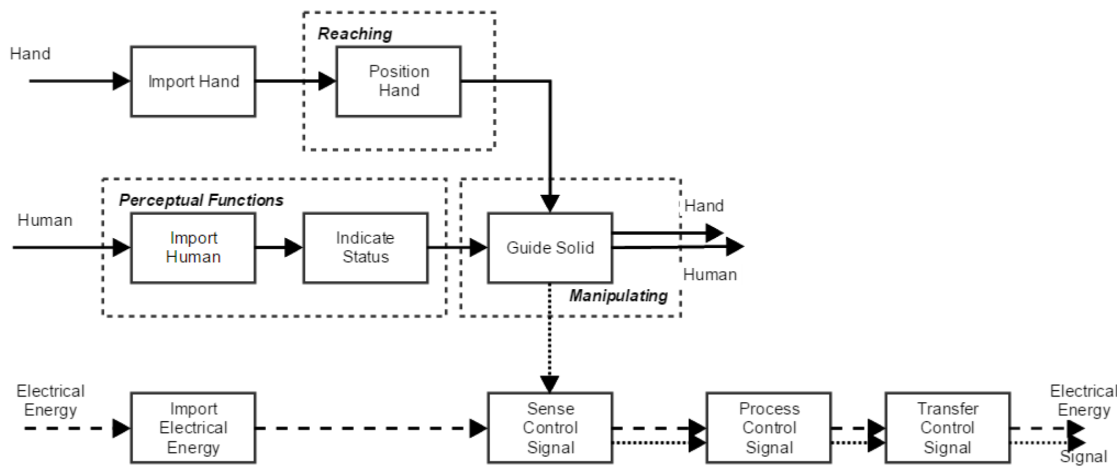


Figure 116. Modified Garden Shears

Case 14: Interfacing with a Product

In order to make products and environments more inclusive, designers should ensure that the product areas the user interacts with, and the correct way to interact with them, are obvious to the user. Many products exclude users, regardless of their level of ability, by requiring unintuitive methods of user interaction. Control panels are typical products that require the user to develop a correct mental model of how the controls will affect the product. Figure 117 depicts an actionfunction model of the high-level functions of a control panel.



Rule Set	User Activity	Product Function	Recommended Change
Clarkson	Perceptual Functions	Interfacing with Product	Morphological

User Activity (ICF Term)	Meaning
Perceptual Functions	Specific mental functions of recognizing and interpreting sensory stimuli. *Inclusions: functions of auditory, visual, olfactory, gustatory, tactile and visuospatial perception, such as a hallucination or illusion*

Figure 117 . Actionfunction Diagram and Rule for Case 14: Interfacing with a Product.

Applying the relevant design rule suggests a morphological change to any functions involving user-product interaction coupled with the 'Perceptual Functions' user activity. The suggested morphological change could be any change to the physical solution of how the control panel presents information to the user. The modified actionfunction diagram is shown below.

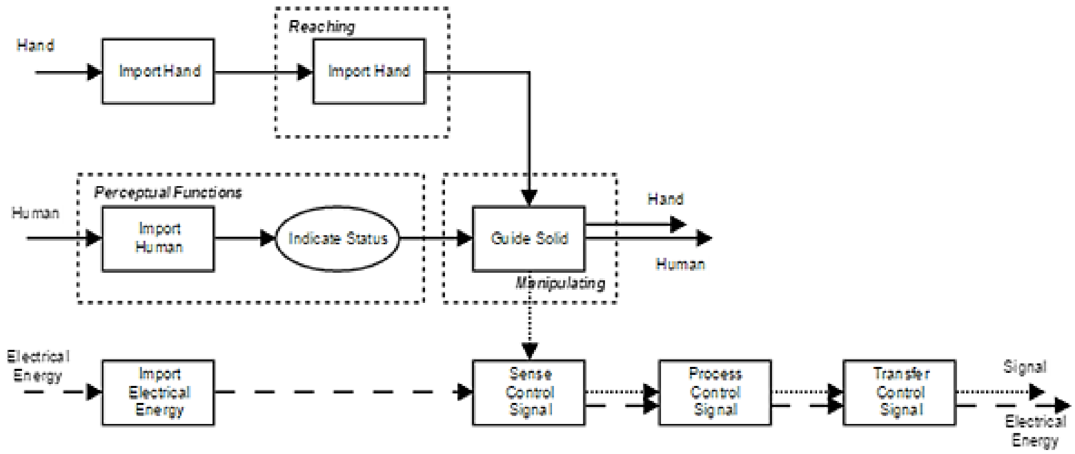
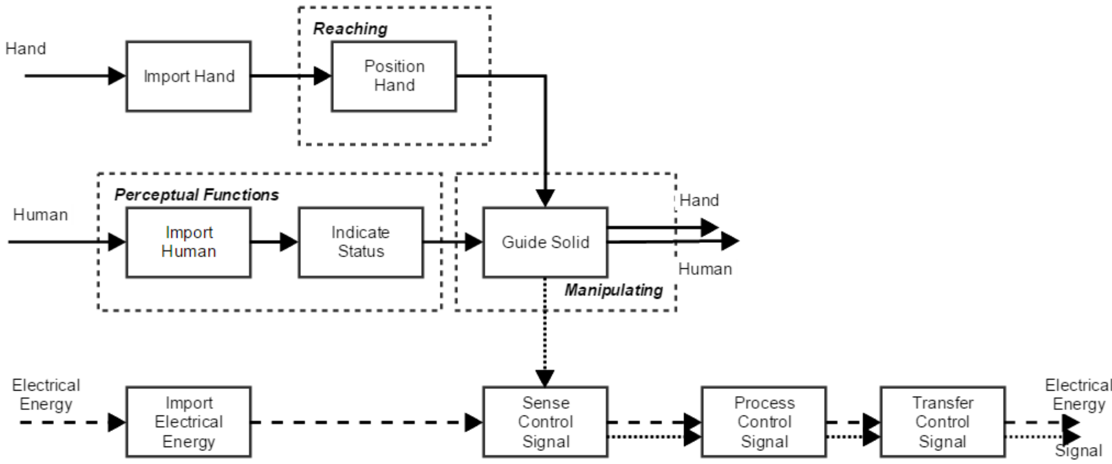


Figure 118. Modified Actionfunction Diagram for Case 14: Interfacing with a Product

The morphological changes suggested by this design rule include alterations to how a product conveys information to users. In order to develop more inclusive products, designers should choose solutions that lead to more intuitive products. Products could utilize alternative forms of communications, such as braille, color-coding, or informative symbols, in order to develop more intuitive, and thus more inclusive, products.

Case 15: Product Feedback

Designers should include functions in their products that allow users to perceive the current state of the product and whether or not their actions have been successful. Adding in feedback functions allows a user to know the status of their interactions with the product, and would lead to more efficient user-product interactions. Control panels are typical products that would be made more inclusive by adding in feedback functions. Figure 109 depicts an actionfunction model of the high-level functions of a control panel.



Rule Set	User Activity	Product Function	Recommended Change
Clarkson	Perceptual Functions	Indicate Feedback	Functional addition

User Activity (ICF Term)	Meaning
Perceptual Functions	Specific mental functions of recognizing and interpreting sensory stimuli. *Inclusions: functions of auditory, visual, olfactory, gustatory, tactile and visuospatial perception, such as a hallucination or illusion*

Figure 119. Modified Actionfunction Diagram for Case 15: Product Feedback

Applying the relevant design rule to the above actionfunction diagram yields to functional addition of a 'Indicate Feedback' function. In this case, the 'Indicate Feedback' function is added, with corresponding 'Perceptual Functions' user activity, after the 'Transfer Control Signal' function to indicate that the product should provide feedback after the first action is completed. This functional addition would allow users to understand the effect of their actions on the product, which would make for a more effective user-product interaction.

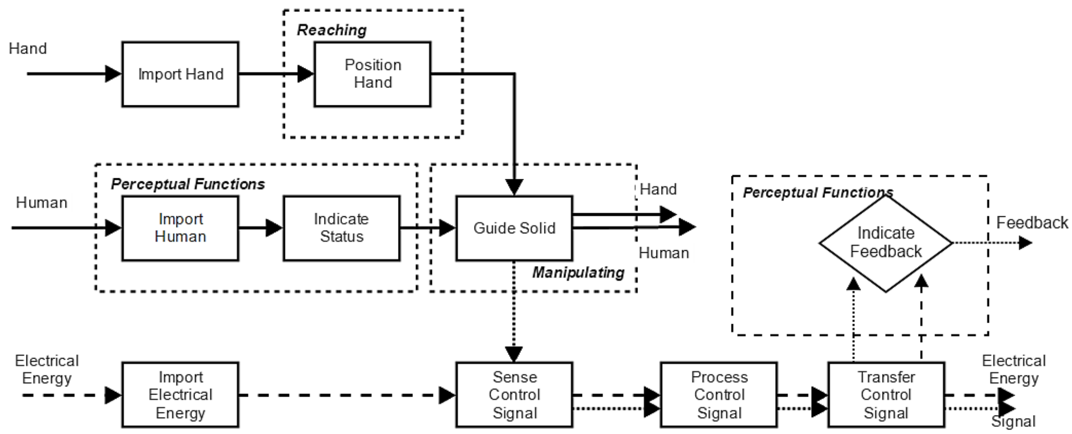
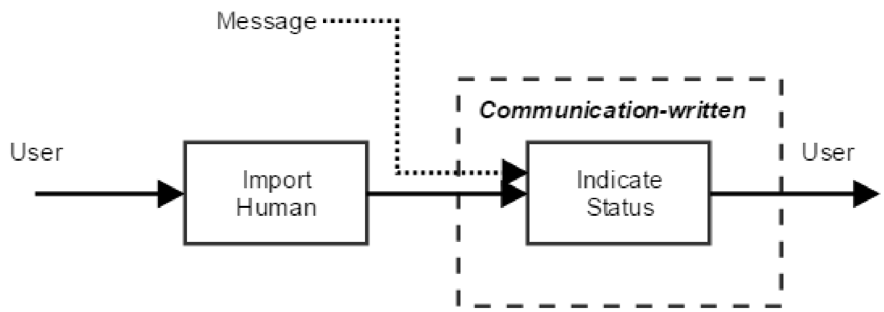


Figure 120. Modified Actionfunction Diagram for Case 15: Product Feedback

Case 16: Alternatives to Writing

In order to develop more inclusive products, designers should provide the potential for feedback to be transmitted by alternate modes (textual, verbal, pictorial, tactile, lights, sounds). The typical written sign can exclude users who do not have good enough eyesight to read it, or who do not speak the language presented on the sign. The actionfunction diagram of the high-level functions related to reading a typical sign is presented below alongside relevant design rules.



Rule Set	User Activity	Product Function	Recommended Change
Clarkson	Perceptual Functions	Indicate Status	Morphological → Communication - various
Sangelkar	Communication – written	Indicate Status	Morphological → Communication - braille

User Activity (ICF Term)	Meaning
Perceptual Functions	Specific mental functions of recognizing and interpreting sensory stimuli. *Inclusions: functions of auditory, visual, olfactory, gustatory, tactile and visuospatial perception, such as a hallucination or illusion*
Communication - written	Comprehending the literal and implied meanings of messages that are conveyed through written language

Figure 121. Actionfunction Diagram and Rule for Case 16: Alternatives to Writing

Applying these two design rules yields similar results. Applying Clarkson's design rule leads to a morphological change to the 'indicate Status' function under the 'Communication-written' user activity. This morphological change leads to a physical change in how the sign conveys its message, and suggests to designers that allowing alternative forms of communication would make the sign more inclusive. The application of Clarkson's rule suggests a broad range of alternative forms of communication in order to develop a more inclusive product. Applying Sangelkar's rule leads to the same suggestion of a morphological change to the 'Indicate Status' function, however Sangelkar's rule is more specific in that it only suggests providing braille as an alternative form of communication. The modified actionfunction diagrams obtained by applying Clarkson's and Sangelkar's relevant design rules can be seen in Figure 122 and Figure 123, respectively.

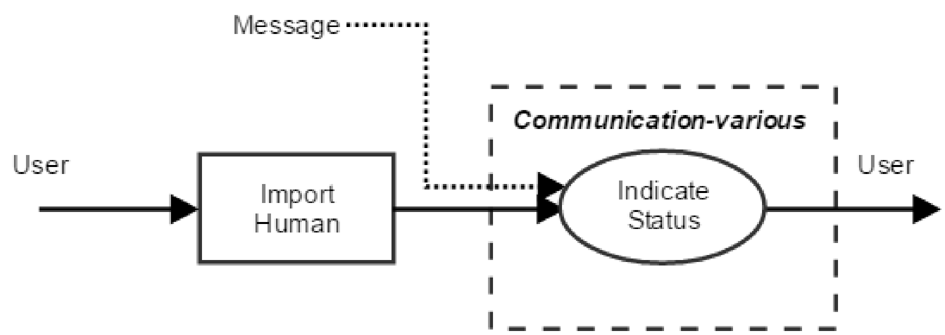


Figure 122. Actionfunction Diagram Modified Using Clarkson's Rule in Case 16

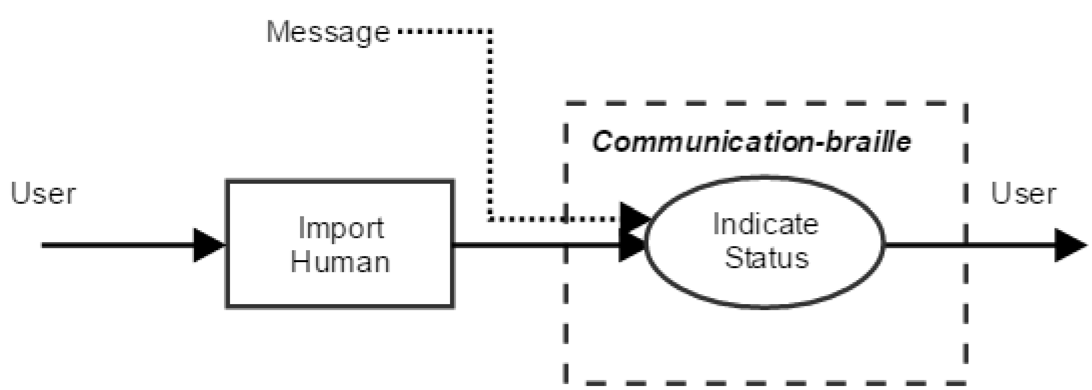
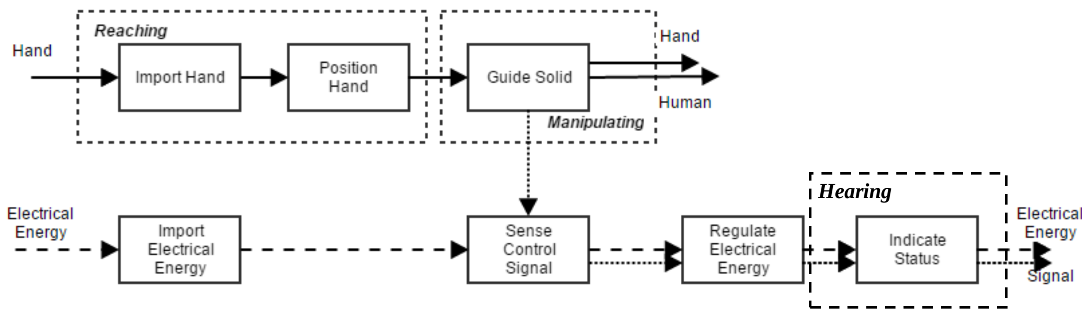


Figure 123. Actionfunction Diagram Modified Using Sangelkar's Rule in Case 16

Case 17: Hearing Parameters

In order to develop more inclusive products, designers should allow users to modify the parameters of audio devices (adjustable volume, pitch, tone duration) to maximize detection. Both Clarkson's and Sangelkar's rule sets contain rules pertaining to parametric changes to 'Indicate Status' functions related to the 'Hearing' user activity, indicating that adjustments to audio devices' volume, pitch, and duration would lead to a more inclusive product. Electronic speakers, as found in many products, involve the generation of noises, and can be made more inclusive through the application of the relevant design rules. Figure 124 contains the actionfunction diagram for a typical speaker and relevant design rules from each rule set.



Rule Set	User Activity	Product Function	Recommended Change
Clarkson	Hearing Functions	Export Signal	Parametric
Sangelkar	Hearing Functions	Indicate Status	Parametric

User Activity (ICF Term)	Meaning
Hearing Functions	Sensory functions relating to sensing the presence of sounds and discriminating the location, pitch, loudness and quality of sounds.

Figure 124. Actionfunction Diagram and Rule for Case 17: Hearing Parameters

Applying the each of the relevant design rules leads to the same result of a parametric change to the 'Indicate Status' function. These changes suggest to designers that changes to the parameters of the speaker, i.e changes to the pitch, volume, or duration, would lead to a more inclusive product. The modified actionfunction diagram of the electronic speaker is shown in Figure 125.

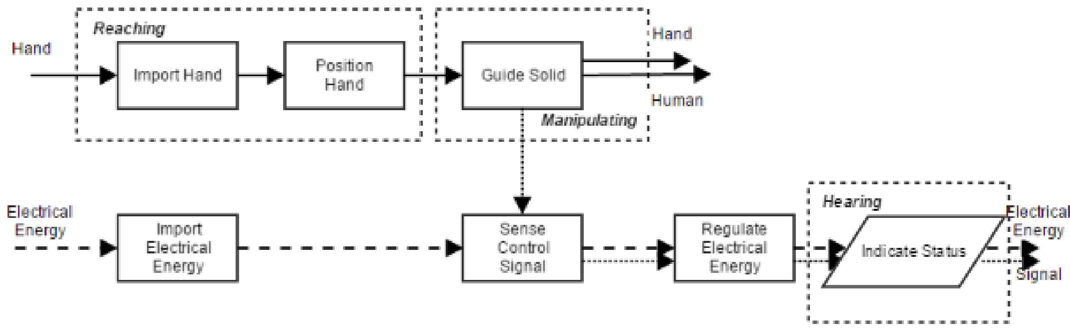
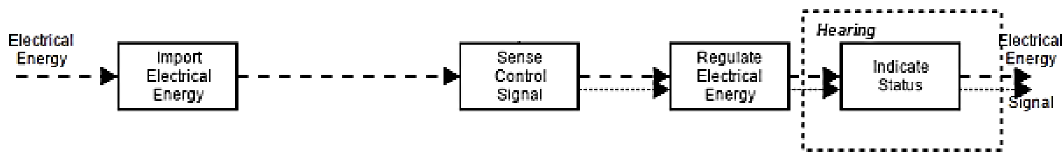


Figure 125. Modified Speaker Actionfunction Diagram for Case 17: Hearing Parameters

The modified speaker actionfunction diagram suggests to designers that, in order to make their products more inclusive, they should consider modifying any speaker's audio parameters such that the sounds the speakers produce can be more readily heard by users of all ability levels.

Case 18: Alternatives to Sound Signals

In order to develop more inclusive audio products, designers should strive to utilize lower pitched, natural tones in comparison to higher pitched, synthesized tones. Additionally, designers should allow for secondary perceptual cues alongside auditory messages. The typical public address system can exclude users with impaired hearing, or those who do not speak the language of the speaker's message. The actionfunction diagram of the high-level functions related to listening to a typical public address system are provided in Figure 126.



Rule Set	User Activity	Product Function	Recommended Change
Clarkson	Hearing Functions	Export Signal	Morphological
Sangelkar	Hearing Functions	Indicate Status	Morphological

User Activity (ICF Term)	Meaning
Hearing Functions	Sensory functions relating to sensing the presence of sounds and discriminating the location, pitch, loudness and quality of sounds.

Figure 126. Actionfunction Diagram and Rule for Case 18: Alternatives to Sound Signals

Applying the each of the relevant design rules leads to the same result of a morphological change to the 'Indicate Status' function under the 'Hearing' user activity. These changes suggest to designers that changes to how the public address system conveys its message would lead to a more inclusive product. The modified actionfunction diagram of the public address system is shown in Figure 127. This morphological change leads to a physical change in how the system conveys its message, and suggests to designers that allowing alternative forms of communication would make the public address system more inclusive. A designer could add in a speech to text display to provide a visual readout of the speaker's message for the hearing impaired, or modify the system to utilize a more natural tone of voice for more clarity. There are many was to provide alternative forms of communication alongside a public address system that would lead to a more inclusive product.

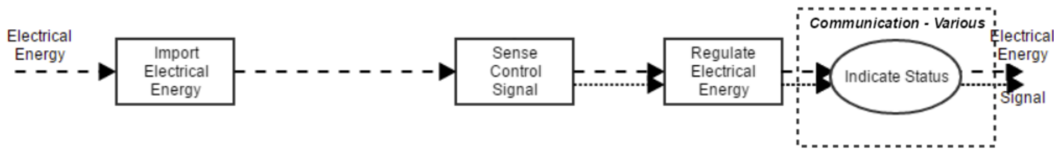
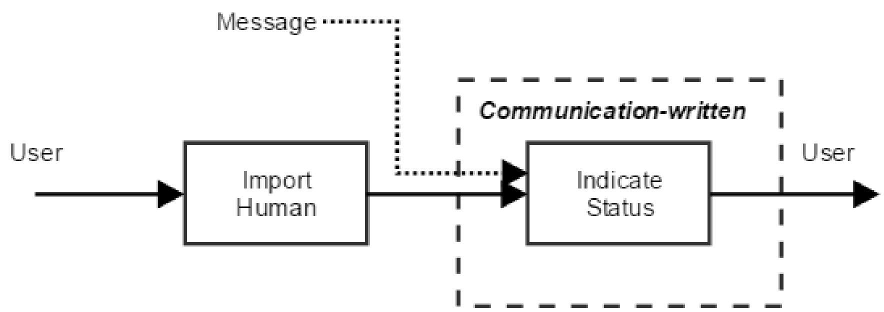


Figure 127. Modified Public Address System Actionfunction Diagram from Case 18

Case 19: Alterations to Text

Users with poor eyesight have difficulties reading small or decorative text. In order to develop more accessible products utilizing texts, designers should strive to employ larger and more legible fonts. Larger, sans-serif fonts are more easily distinguished by users with impaired eyesight than decorative or cursive font styles. Additionally, designers should use plain, instead of patterned, backgrounds whenever possible to aid users in distinguishing text from the background. Figure 128 contains a segment of an actionfunction diagram pertaining to how a user would read text in various products.



Rule Set	User Activity	Product Function	Recommended Change
Clarkson	Communication -written	Indicate Status	Parametric

User Activity (ICF Term)	Meaning
Communication - written	Comprehending the literal and implied meanings of messages that are conveyed through written language

Figure 128. Actionfunction Diagram and Rule for Case 19: Alterations to Text

The relevant design rule suggests a parametric change to the 'Indicate Status' function under the 'Communication-written' user activity. This parametric change entails the changes required to make text more legible, and thus more accessible. The modified actionfunction diagram is shown in Figure 129.

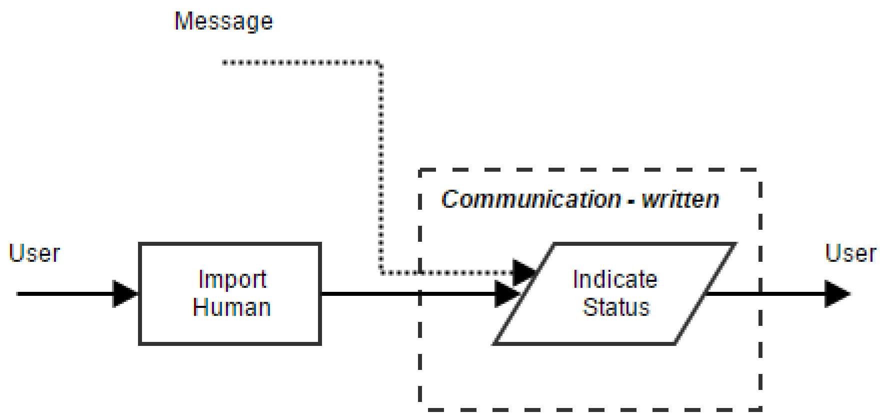
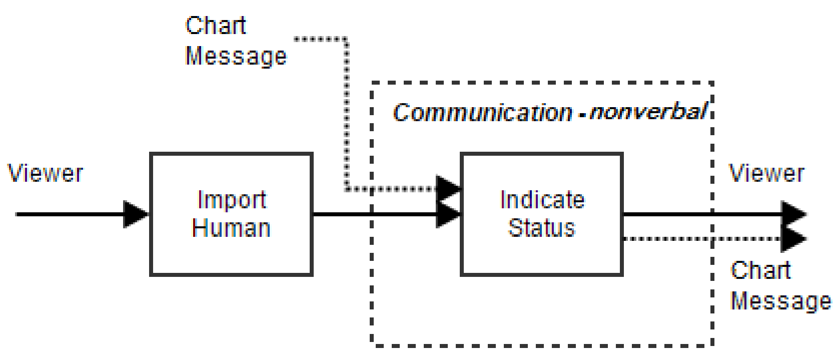


Figure 129. Text Actionfunction Diagram Modified Using Clarkson's Rule in Case 19

The parametric changes suggested by Clarkson's design rule of (Indicate Status, Communication – written) → (Parametric) include modifications to the text size, font type, and background style. Modifying these parameters would help to make text more legible and accessible to sight-impaired users.

Case 20: Alterations to Charts and Images

Users with poor eyesight have difficulties reading and differentiating low contrast or small graphical symbols. Additionally, designers should keep all the forms of color blindness when setting the color palette of a product. Figure 130 shows the actionfunction diagram of a typical chart, which visually impaired users would have difficulty reading without modifications.



Rule Set	User Activity	Product Function	Recommended Change
Clarkson	Communication -nonverbal	Indicate Status	Parametric
Sangelkar	Seeing	Indicate Status	Parametric

User Activity (ICF Term)	Meaning
Seeing Functions	Sensory functions relating to sensing the presence of light and sensing the form, size, shape and color of the visual stimuli.
Communication - nonverbal	Comprehending the literal and implied meanings of messages conveyed by gestures, symbols and drawings

Figure 130. Actionfunction Diagram and Rules for Case 20: Alterations to Charts and Images

Applying both Clarkson's and Sangelkar's rules lead the same resulting, modified actionfunction diagram. Clarkson's rule applies directly in this situation, whereas Sangelkar's rule requires some inference, relating the 'Communication – nonverbal' user activity to the 'Seeing' user activity referenced in Sangelkar's rule. Applying these rules leads to the resulting actionfunction diagram in Figure 131.

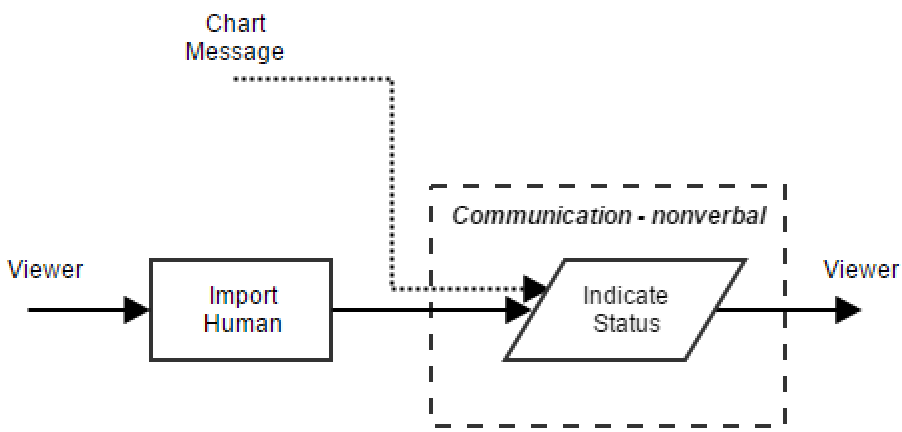
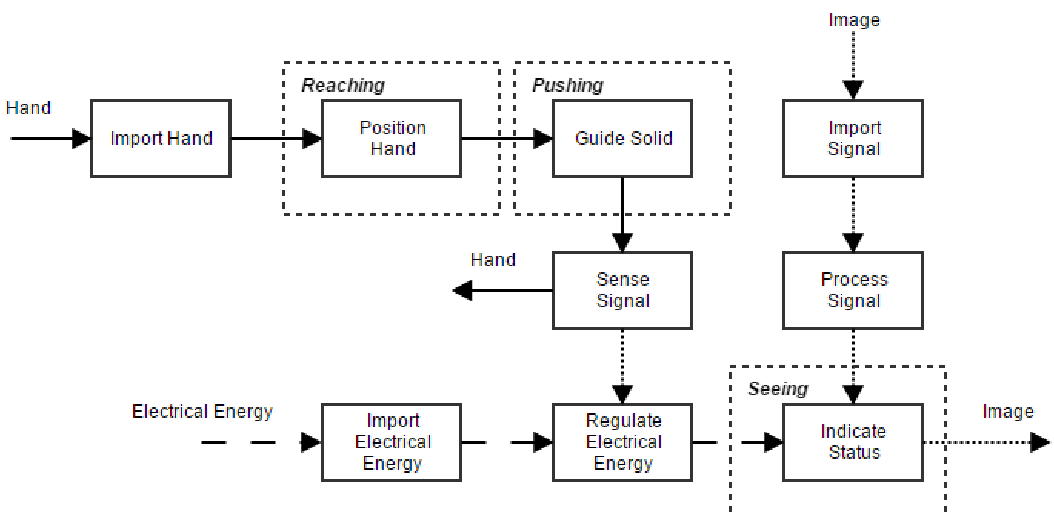


Figure 131. Modified Actionfunction Diagram for Case 20: Alterations to Charts and Images

The parametric changes suggested by the application of these rules could include modifications to the color scheme, image sizes, or contrast levels. Modifications to the chart parameters would lead to a more legible and accessible chart or image. These design rules can be utilized by designers on any product involving informative graphics or charts in order to help users understand their meaning.

Case 21: Anti-Glare Screen

In order to make environments and products more accessible to all users, designers should consider reducing glare by avoiding highly reflective surfaces and allowing for light sources and screens to be easily repositioned. Consider the typical computer or television screen. In many environments, glare makes the screen unreadable for a large amount of users. The actionfunction diagram for a typical screen is pictured below in Figure 132.



User Activity	Product Function	Recommended Change
Seeing	Indicate Status	Morphological

User Activity (ICF Term)	Meaning
Seeing Functions	Sensory functions relating to sensing the presence of light and sensing the form, size, shape and color of the visual stimuli.

Figure 132. Actionfunction Diagram and Rules for Case 21: Anti-Glare Screen

Applying the relevant design rule to the actionfunction diagram of the screen results in a morphological change to the ‘Indicate Status’ function under the ’Seeing’ user activity. This modification suggests physical changes to the screen to modify how the screen indicates information to the user. In order to create a more accessible scree, designers should incorporate solutions to the issues of glare and repositionability. The modified actionfunction diagram is shown in Figure 133.

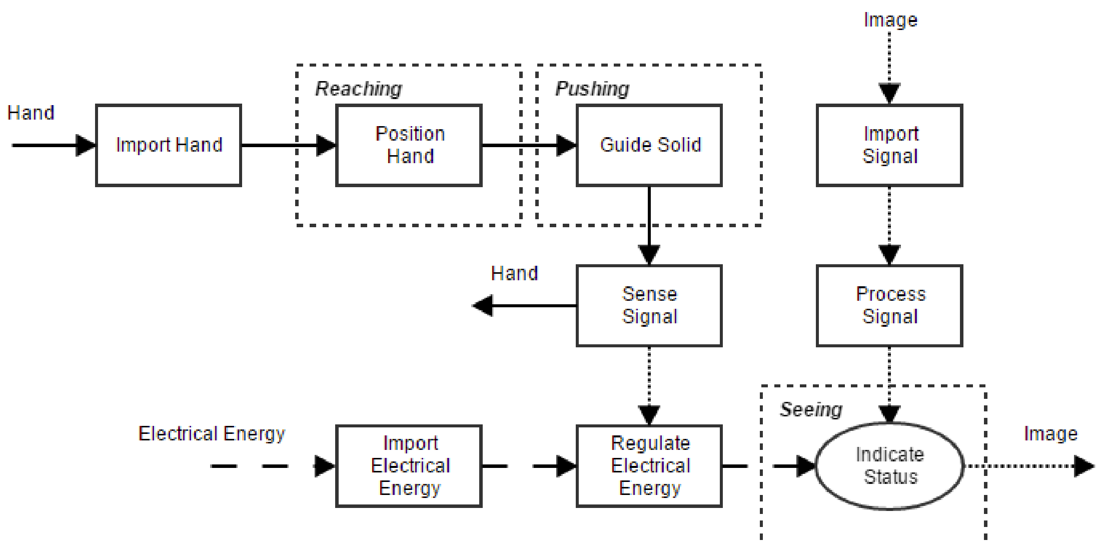
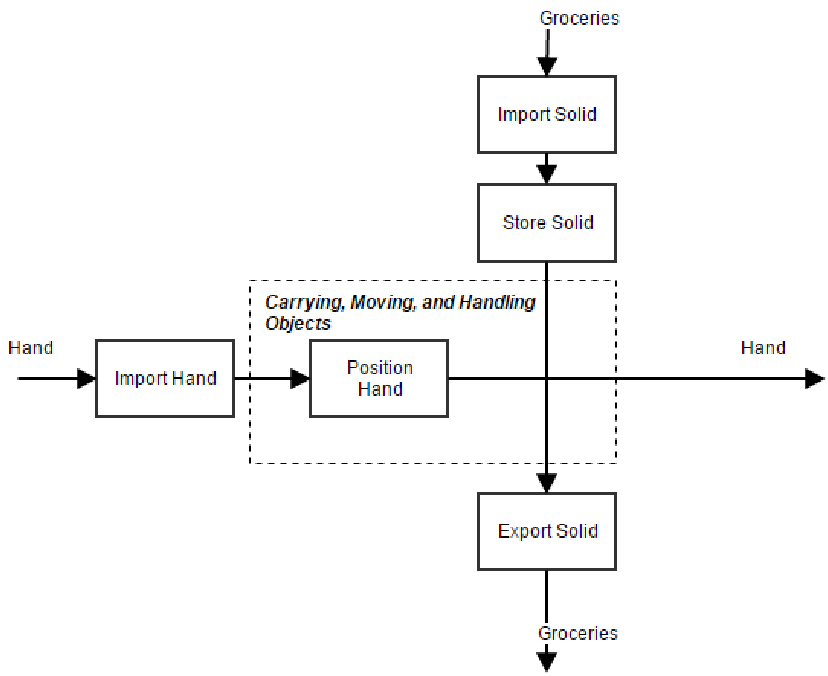


Figure 133. Modified Actionfunction Diagram for Case 21: Anti-Glare Screen

Case 22: Grocery Bag

In order to make environments and products more accessible to all users, designers should consider changes to how a user positions their hands on the product to move or otherwise handle the object. Users with upper body disabilities will have difficulty grasping or carrying certain shapes of objects, so designers should consider parametric changes in order to develop more inclusive products. In this case, we apply the given design rule to the actionfunction diagram of a typical grocery bag, provided in Figure 134.



Rule Set	User Activity	Product Function	Recommended Change
Sangelkar	Carrying, Moving, Handling Objects	Position Hand	Parametric

User Activity (ICF Term)	Meaning
Carrying, Moving, and Handling Objects	Using the hands or arms to carry or move objects. Includes actions such as *Pulling*, *Pushing*, *Reaching*, and *Turning*

Figure 134. Actionfunction Diagram and Rule for Case 22: Grocery Bag

Applying the corresponding design rule to the actionfunction diagram of the grocery bag results in a parametric change to the 'Position Hand' function under the 'Carrying, Moving, and Handling Objects' user activity. Changing the parameters of how the user grips and carries the bag would help to make a more accessible product. The modified actionfunction diagram in shown in Figure 135.

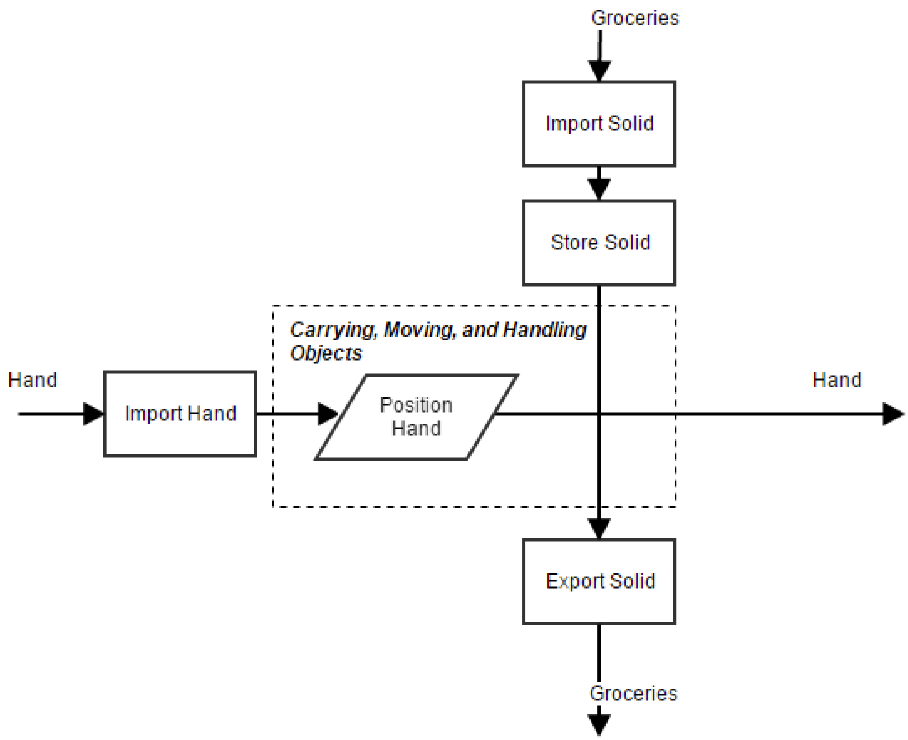


Figure 135. Modified Actionfunction Diagram for Case 22: Grocery Bag

Holding and carrying a grocery bag can be difficult for several reasons. The handles are narrow and do not provide much room for gripping, and the handle can cut into the users hand. A possible solution designers could implement is a hard carrying handle that can attach to grocery bags. This proposed solution, pictured in Figure 136, utilizes a U-shaped hard plastic tube with a slot to fit bag handles into. This tube also has a silicone outer sheath, for a more comfortable grip while the user carries the bag. This design, suggested by modifications from the relevant design rule in Figure 134, would allow users with hand impairments or other disabilities to grip multiple grocery bags comfortably in one hand.

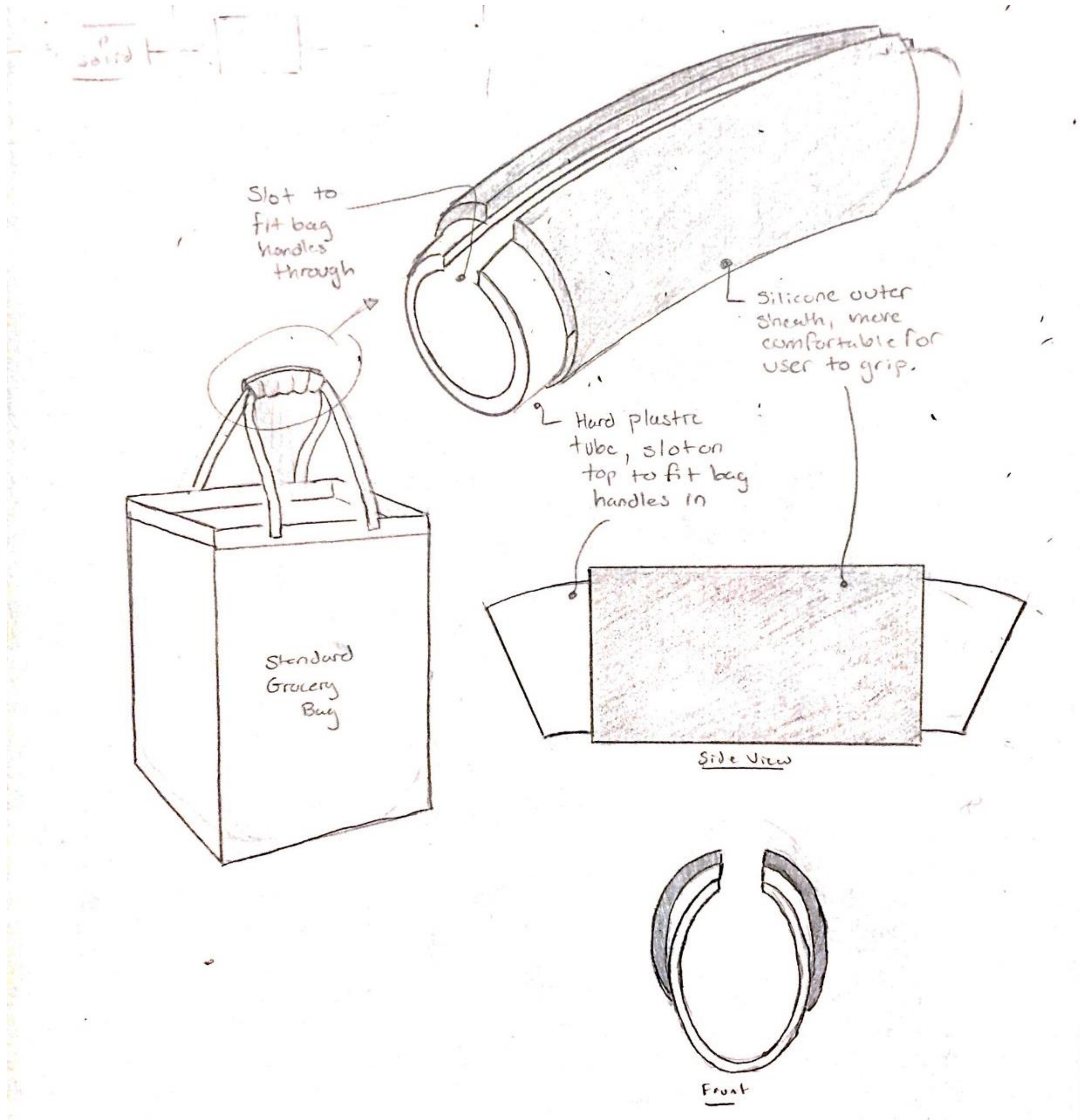
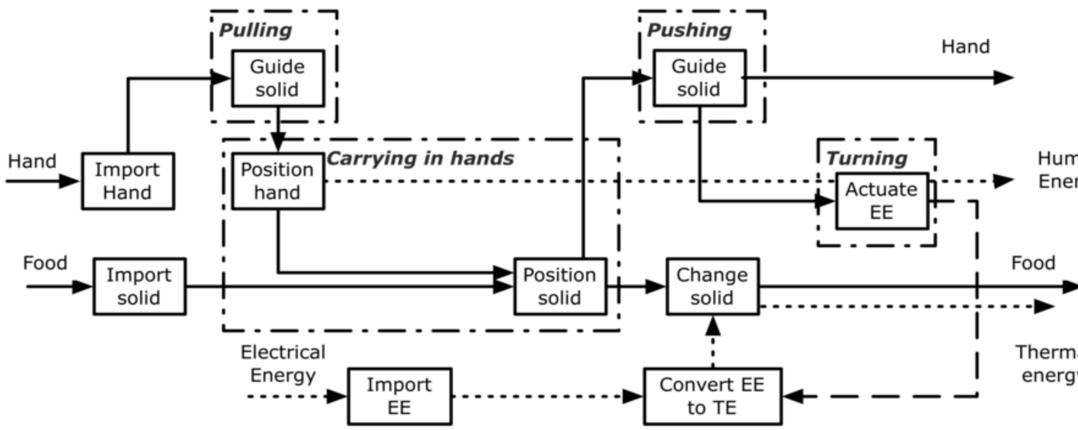


Figure 136. Modified Grocery Bag Holder

Case 23: Microwave

In order to make environments and products more accessible to all users, designers should consider how users move and position objects in a system. Users with upper body disabilities will have difficulty grasping or carrying certain shapes of objects, or handling objects inside areas that are too small, so designers should consider parametric changes in order to develop more inclusive products. It may be difficult for impaired users to manipulate their hands and arms in the tight confines of typical microwaves. In this case, we apply the given design rule to the actionfunction model of a typical microwave, pictured in Figure 137.



Rule Set	User Activity	Product Function	Recommended Change
Sangelkar	Carrying, Moving, Handling Objects	Position Solid	Parametric

User Activity (ICF Term)	Meaning
Carrying, Moving, and Handling Objects	Using the hands or arms to carry or move objects. Includes actions such as *Pulling*, *Pushing*, *Reaching*, and *Turning*

Figure 137. Actionfunction Diagram and Rule for Case 23: Microwave

Applying Sangelkar's relevant design rule yields the modified actionfunction diagram of Figure 138. Sangelkar's rule suggests a parametric change is necessary to the 'Position Hand' function under the 'Carrying in hands' user activity in order to develop a more inclusive product.

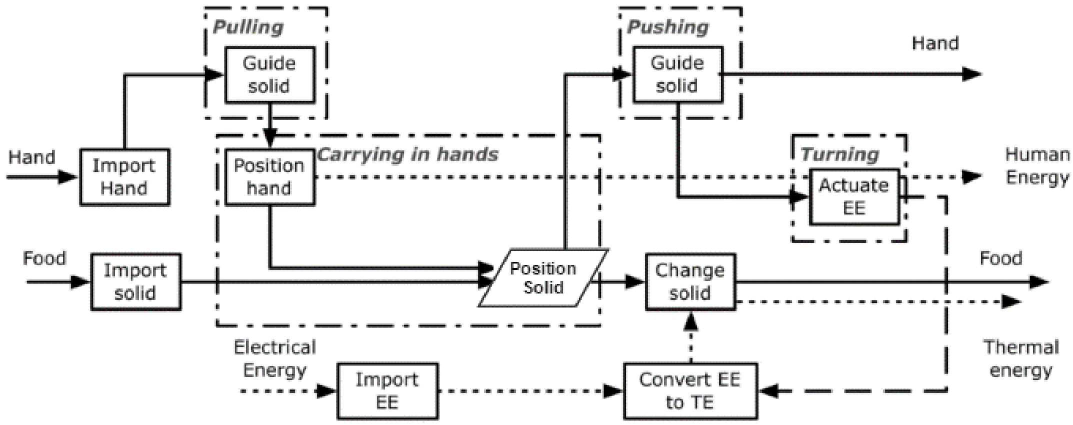


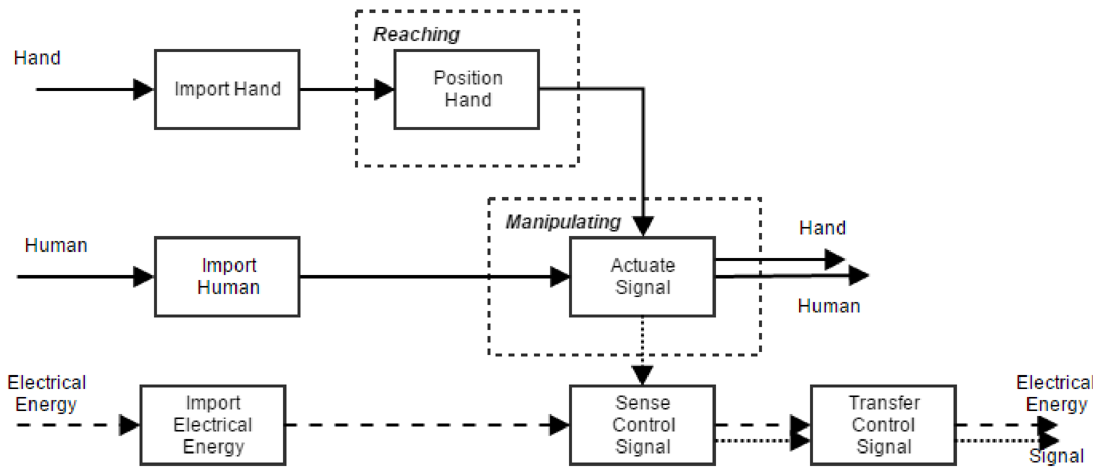
Figure 138. Modified Actionfunction Diagram for Case 23: Microwave

The parametric change suggested by the rule in Case 23 could include adjustments to the size of the microwave chamber, or modifications to parameters in the door to allow the chamber to open wider. Sangelkar's rule in Case 23 suggests modifications that would effectively make for a more inclusive product for impaired users.

Case 24: Push Button

In order to make products with controls more accessible to all users, designers should consider utilizing push buttons rather than other forms of control switches such as toggles and dials. Push buttons are far easier for users with impaired hands to actuate than rotating dials or toggle switches, as the motion of pushing is far simpler and more easily accomplished than gripping and twisting. Figure 139 contains the actionfunction diagram for a general power switch, be it a toggle or dial switch, as well as a relevant design rule.

Applying the relevant design rule in this case yields a morphological change to the way



Rule Set	User Activity	Product Function	Recommended Change
Sangelkar	Manipulating	Actuate Signal	Morphological → Pushing

User Activity (ICF Term)	Meaning
Manipulating	Using fingers and hands to exert control over, direct or guide something, such as when handling coins or other small objects.

Figure 139. Actionfunction Diagram and Rule for Case 24: Push Button

the 'Actuate Signal' function is accomplished. This change serves the purpose to change the related user activity from 'Manipulating' - which includes the user activities related to pushing, pulling, gripping and rotating with the hands – to the more specific use activity of 'Pushing'. AS mentioned previously, this change is suggested as the ‘Pushing’ user activity is easier to accomplish and more inclusive than other activities that fall under the ‘Manipulating’ user activity. The modified actionfunction diagram is pictured in Figure 140.

Sangelkar’s design rule, in the case of a general switch, suggests that, in order to develop

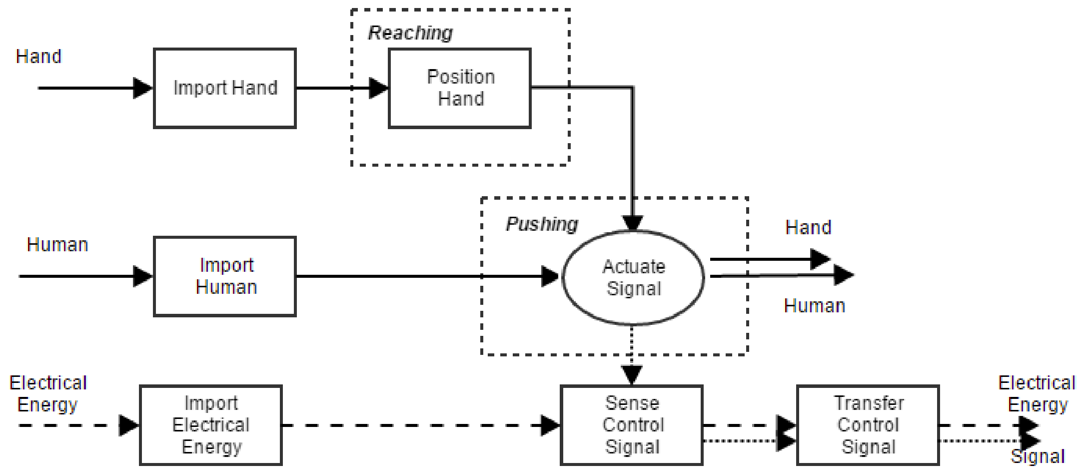
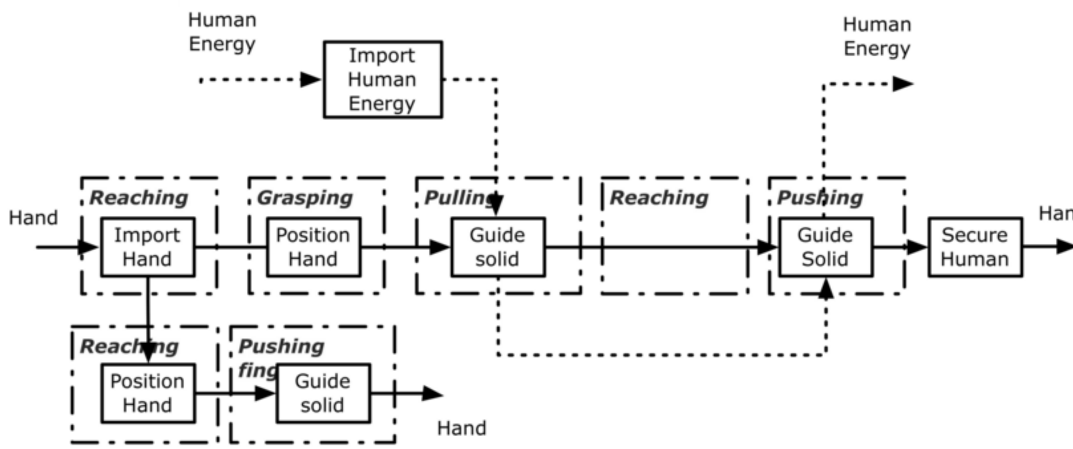


Figure 140. Modified Switch Actionfunction Diagram

a more inclusive product, designers should strive to utilize push buttons instead of other types of switches. Push buttons can be actuated by any appendage, and require no grip strength or fine motor skills to operate, and thus are more inclusive than other types of switches.

Case 25: Seat Belt

In order to make products more accessible to all users, designers should consider changing certain parameters of the product relating to how a user would grip and guide parts of the product. Individuals with reduced grip strength may have difficulties manipulating small or unfamiliarly shaped objects. In this case, we consider the following actionfunction diagram of a seat belt and apply the given design rules. These design rules are grouped as they are all closely related and involve the same type of changes.



Rule Set	User Activity	Product Function	Recommended Change
Sangelkar	Manipulating	Guide Solid	Parametric
Sangelkar	Manipulating	Position Hand	Parametric
Sangelkar	Pushing with fingers	Guide Solid	Parametric

User Activity (ICF Term)	Meaning
Manipulating	Using fingers and hands to exert control over, direct or guide something, such as when handling coins or other small objects. Includes *Grasping*, *Pushing* and like activities.
Pushing	Using fingers, hands and arms to move something from oneself, or to move it from place to place

Figure 141. Actionfunction Diagram and Rule for Case 25: Seat Belt

Applying the relevant design rules yields parametric changes to the 'Position Hand' function under the 'Grasping' user activity, the 'Guide Solid' function under the 'Pushing with

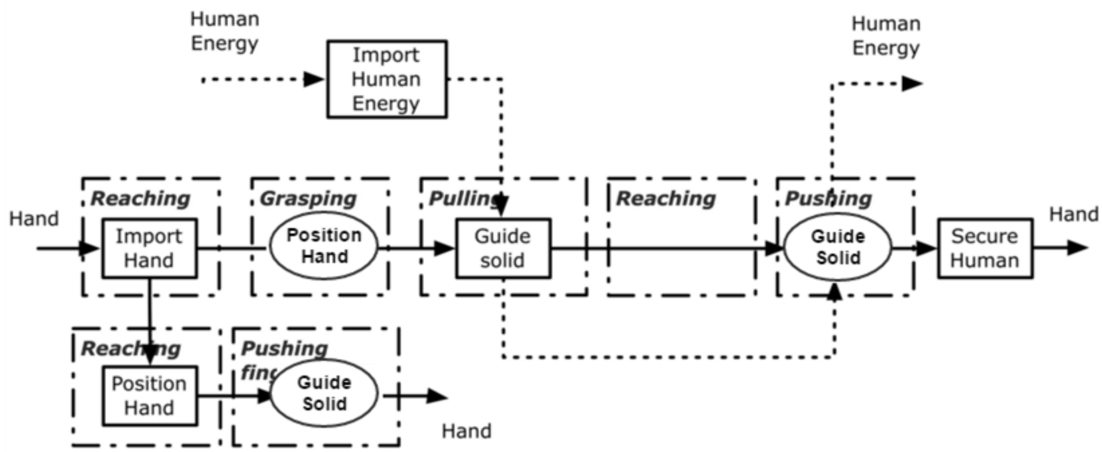


Figure 142. Modified Seat Belt Actionfunction Diagram

fingers' user activity, and to the 'Guide Solid' function under the 'Pushing' and 'Pulling' user activities. The modified actionfunction diagram is shown in Figure 142.

The parametric changes that Sangelkar's rules suggest are all aimed at making the actions of gripping, latching, and unlatching the seat belt more inclusive. These modified functions can be physically represented by the sketched seat belt in Figure 143. This modified seat belt has an oversized ergonomic handle for easier positioning of the user's hand. Additionally, the modified seat belt utilizes an extended push button with a stepped design which allows the user to more easily brace their fingers against the bottom of the seat belt latch while pushing down on the button. Additionally, the larger push button provides a larger area for the user to press on, so that they can use their hand, palm, or various other appendages to push rather than just their fingers.

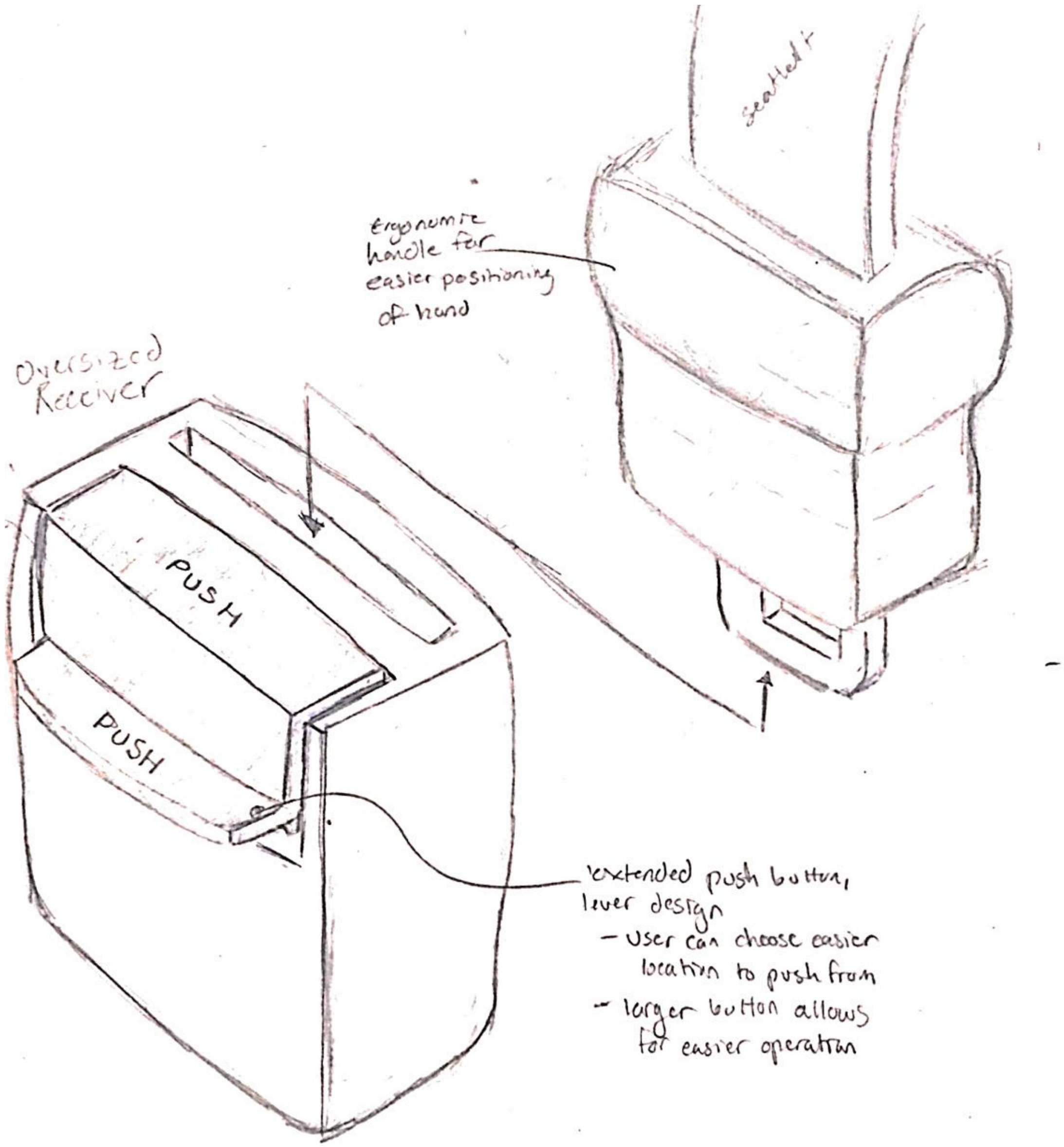
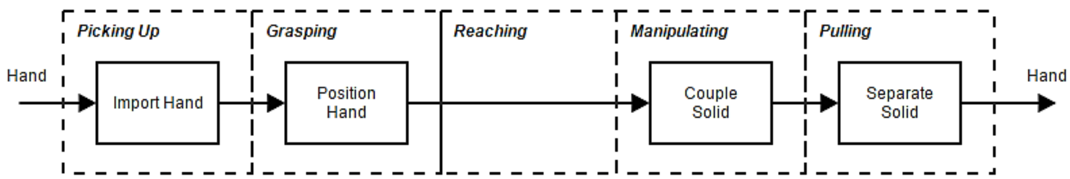


Figure 143. Modified Seat Belt for Case 25

Case 26: Extended Razor

In order to make products more accessible to all users, designers should consider changing certain parameters of the product relating to how a user brings the product in contact with other objects. In this case, we consider a typical shaving razor, for which the actionfunction diagram is pictured in Figure 144. Users need to couple the product with their leg or other body parts in order to cut hair.



Rule Set	User Activity	Product Function	Recommended Change
Sangelkar	Manipulating	Couple Solid	Parametric

User Activity (ICF Term)	Meaning
Manipulating	Using fingers and hands to exert control over, direct or guide something, such as when handling coins or other small objects. Includes *Grasping*, *Pushing* and like activities.

Figure 144. Actionfunction Diagram and Rule for Case 26: Extended Razor

Applying Sangelkar's relevant design rule to the razor's actionfunction diagram yields a parametric change to the 'Couple Solid' function under the 'Manipulating' user activity. This change should make coupling the razor with the user's limbs much easier, and therefore lead to a more inclusive product. The modified actionfunction diagram is pictured in Figure 145.

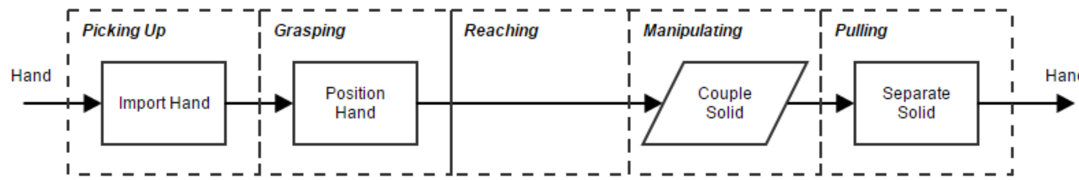


Figure 145. Modified Razor Actionfunction Diagram

The parametric change suggested by Sangelkar's relevant design rule leads designers to modify product parameters relating to how the user couples the razor with their limbs. In this case, these modifications can be represented by the modified, extended handle razor in Figure 146.

The extended handle razor allows a user to attach a standard sized razor to an ergonomic extended handle. The added length from the extended handle allows users to use the razor on farther to reach locations of their body without having to physically reach with their arms as much as they would with a typical razor. This modification should make coupling the razor with the user's limbs much easier, and therefore leads to a more inclusive product.

Case 27: Clothes Iron

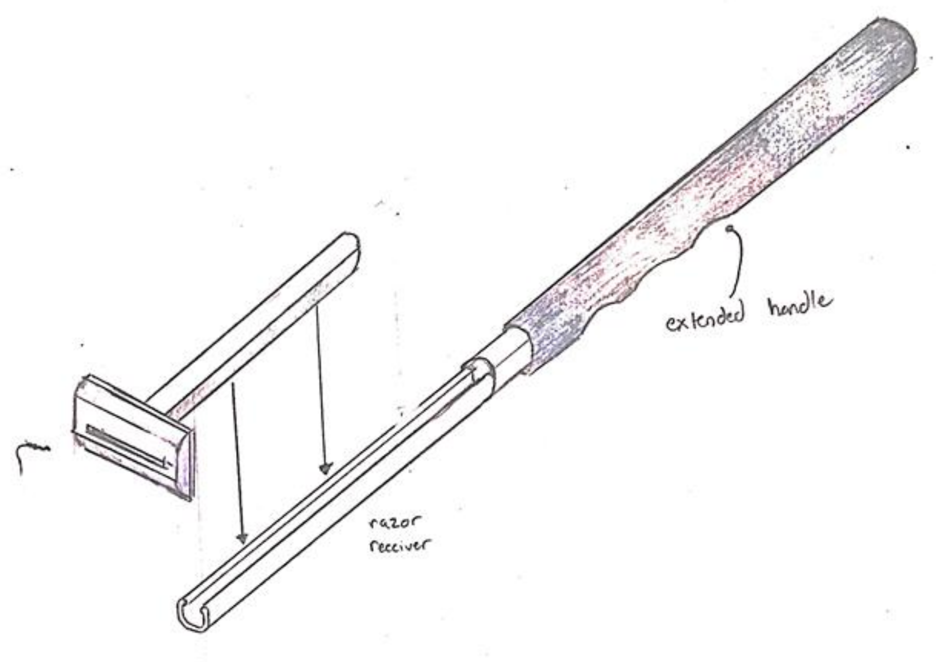
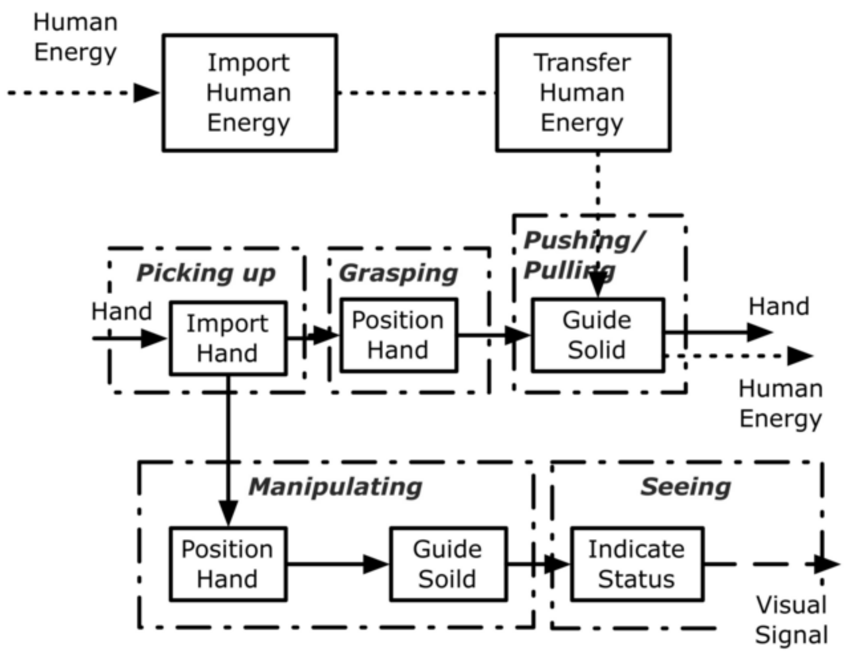


Figure 146. Modified Extended Handle Razor

In order to make products more accessible to all users, designers should consider changing certain parameters of the product relating to how a user guides a part of the product by pulling. Persons with upper body disabilities may not have the proper strength required to pull part of a product, and parametric changes may lead to a better situation. In this case we apply the given design rule to the actionfunction diagram of a typical iron, pictured below.

Applying the relevant design rule in this case yields a parametric change to the 'Guide Solid' function under the 'Pushing/Pulling' user activity. Users with upper body impairments



Rule Set	User Activity	Product Function	Recommended Change
Sangelkar	Pulling	Guide Solid	Parametric

User Activity (ICF Term)	Meaning
Pulling	Using fingers, hands and arms to bring an object towards oneself, or to move it from place to place.

Figure 147. Actionfunction Diagram and Rule for Case 27: Clothes Iron

could have difficulty moving the iron due to its weight. The parametric changes suggested by Sangelkar's rule should lead designers to developing a more inclusive product. The modified actionfunction diagram from applying the relevant design rule is shown in Figure 148.

The parametric change to the 'Guide Solid' function can be accomplished by modifying the overall size and weight of the clothes iron. By utilizing lighter-weight materials and lowering the overall size of the product, designers can develop a clothes iron that is easier for all users, impaired or able, to use.

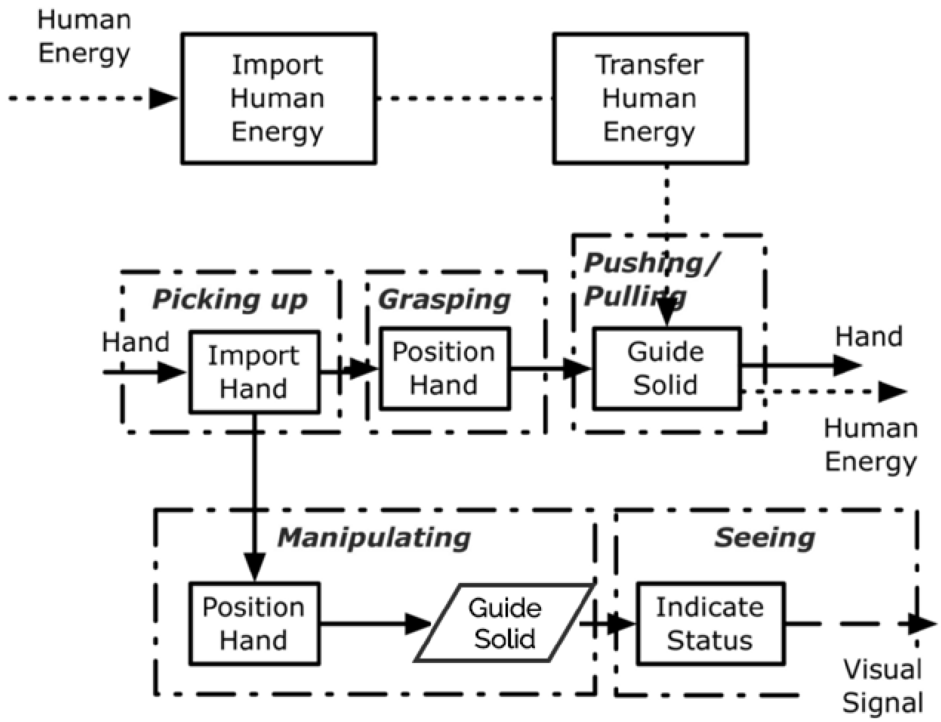
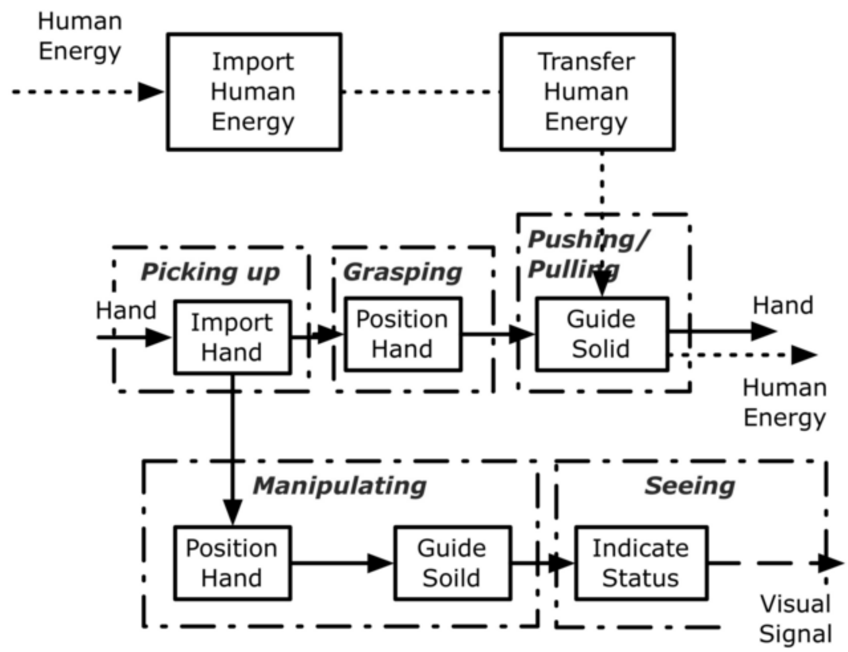


Figure 148. Modified Clothes Iron Actionfunction Diagram for Case 27

Case 28: Automatic Clothes Iron

Designers should consider users with upper body disabilities, or otherwise reduced upper body strength, when developing products that require the user to pull and guide some portion of the product. By enacting some morphological change, designers can alter the product so that the moving parts are no longer associated with a user activity, and are instead accomplished by the product itself. In this case, we consider the typical clothes iron, for which the actionfunction and related rule are provided in Figure 149.

Sangelkar's rule suggests that a morphological change to the 'Guide Solid' function under



Rule Set	User Activity	Product Function	Recommended Change
Sangelkar	Pulling	Guide Solid	Morphological

User Activity (ICF Term)	Meaning
Pulling	Using fingers, hands and arms to bring an object towards oneself, or to move it from place to place.

Figure 149. Actionfunction Diagram and Rule for Case 28: Automatic Clothes Iron

the 'Pulling' user activity would lead to a more inclusive product. Applying Sangelkar's design rule to the actionfunction diagram of a typical clothes iron yields the actionfunction diagram in Figure

150. In this case, we have decided to implement an electrically powered iron to eliminate the need for users to physically guide the iron. This new method of moving the iron leads to the functional additions of ‘Import Electrical Energy’ and ‘Actuate Electrical Energy’ functions pertaining to how the system is powered. Additionally, since the new electrically actuated iron has taken a very different overall shape than the original iron, we have instituted a morphological change to how the user positions their hand when grasping the product. The functional addition of a ‘Position Solid’ function and associated ‘Pulling’ user activity represents how the user can reposition and extend the track the electrically actuated iron moves on.

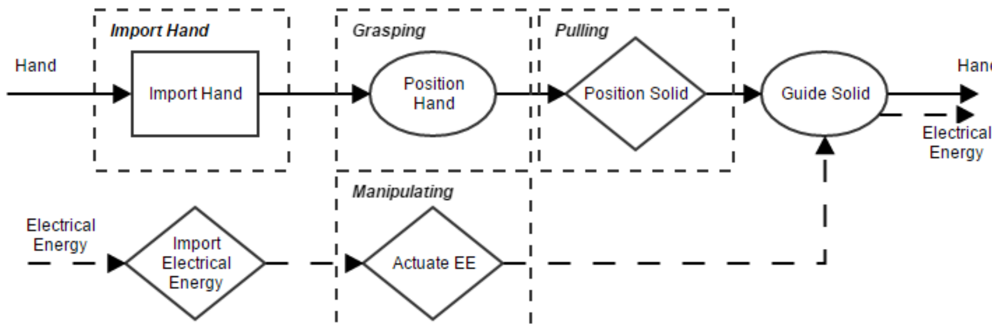


Figure 150. Modified Clothes Iron Actionfunction Diagram for Case 28

The morphological change from Sangelkar’s rule suggests a change to how the ‘Guide Solid’ function, which relates to how a user guides the iron across their clothes. As previously mentioned, in this case we have chosen to represent this change by transforming the typical, manually operated iron into an electrically actuated, automatic clothes iron. The modified automatic clothes iron is pictured in Figure 151. This new product utilizes a heated ironing surface attached to a motor mounted on extendable rails. These rails are connected to two heavy end blocks with non-skid rubber feet, which stabilize the whole system. The user operates this automatic clothes iron by first extending the rails to the proper position to fully cover the clothes they are ironing. The user then actuates the power switch to power the system, after which the user can guide the automatic ironing head by using the two corresponding arrow shaped switches.

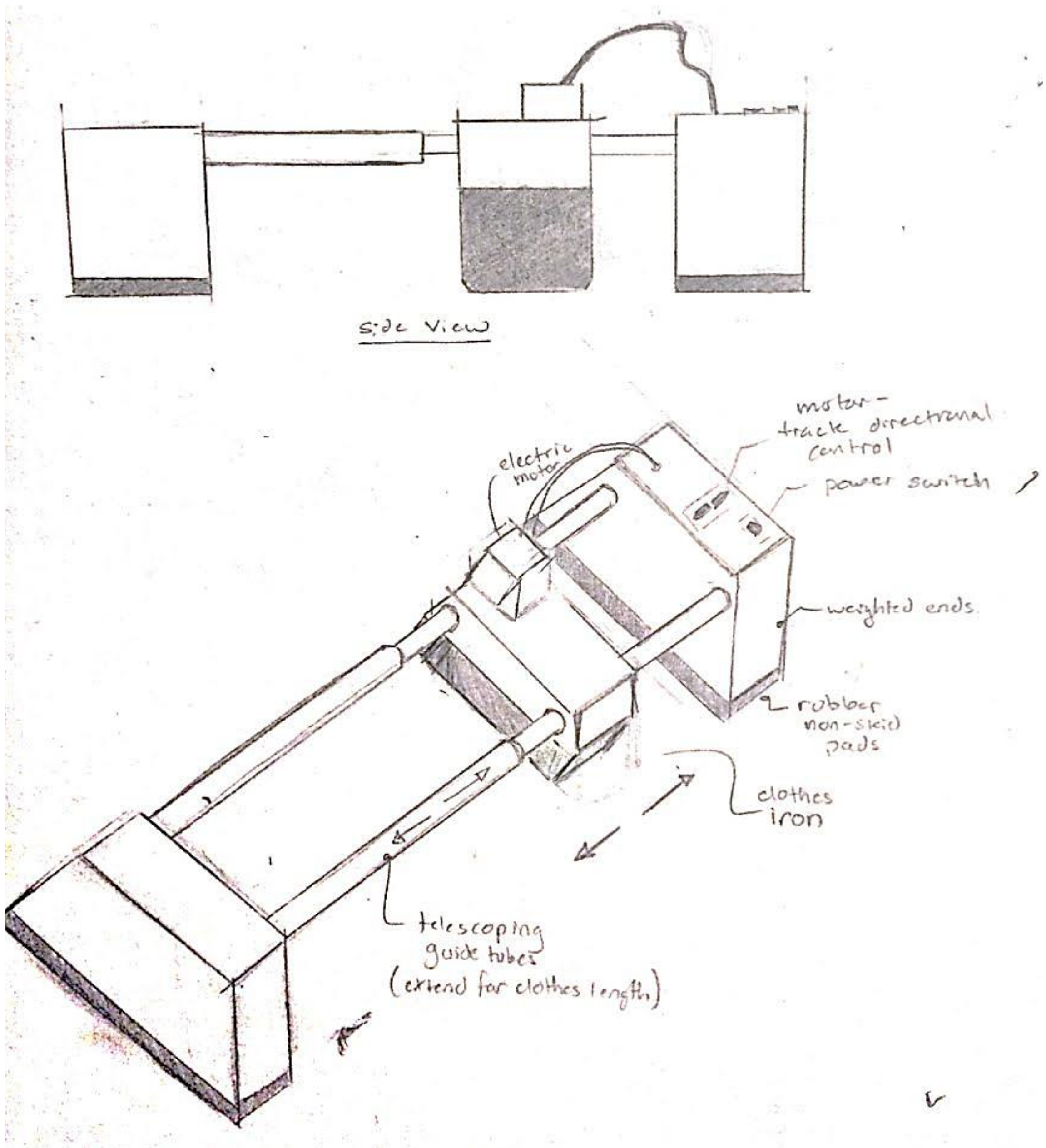
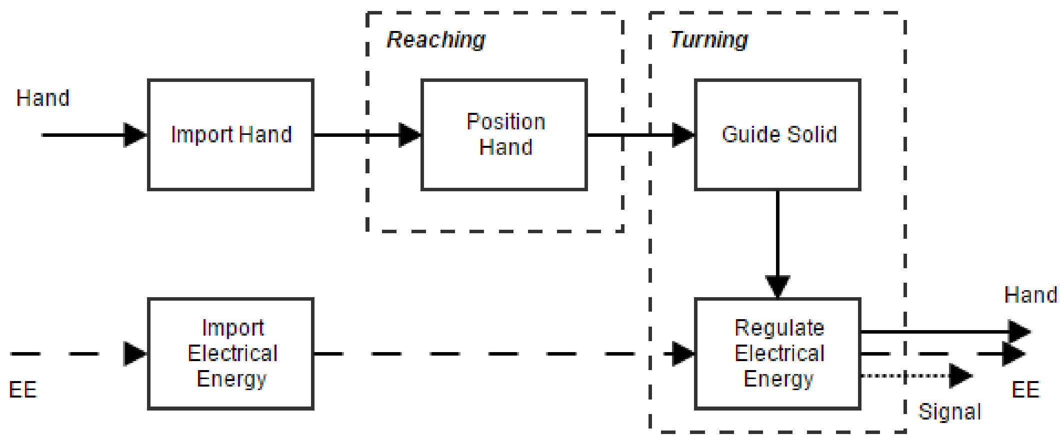


Figure 151. Modified Automatic Clothes Iron

Case 29: Turn Switches

Designers should consider users with diminished hand strength when designing turn switches on products. Users with reduced hand function have more difficulties grasping and twisting objects in comparison to pushing them. Designers can change the parameters of a product to create a mechanical advantage such that users can cause an object to turn by pushing on the end of it. Figure 152 contains the actionfunction diagram for a typical turn switch as well as a relevant design rule.

Applying Sangelkar's design rule to the typical turn switch actionfunction diagram yields



Rule Set	User Activity	Product Function	Recommended Change
Sangelkar	Turning	Regulate Electrical Energy	Parametric

User Activity (ICF Term)	Meaning
Turning	Using fingers, hands and arms to rotate, turn or bend an object, such as is required to use tools or utensils.

Figure 152. Actionfunction Diagram and Rule for Case 29: Turn Switches

a parametric change to the 'Regulate Electrical Energy' function under the 'Turning' user activity. This change suggests that changing certain parameters of the turn switch would allow users to actuate the switch by pushing and therefore make the product more inclusive. The modified actionfunction diagram can be seen in Figure 153.

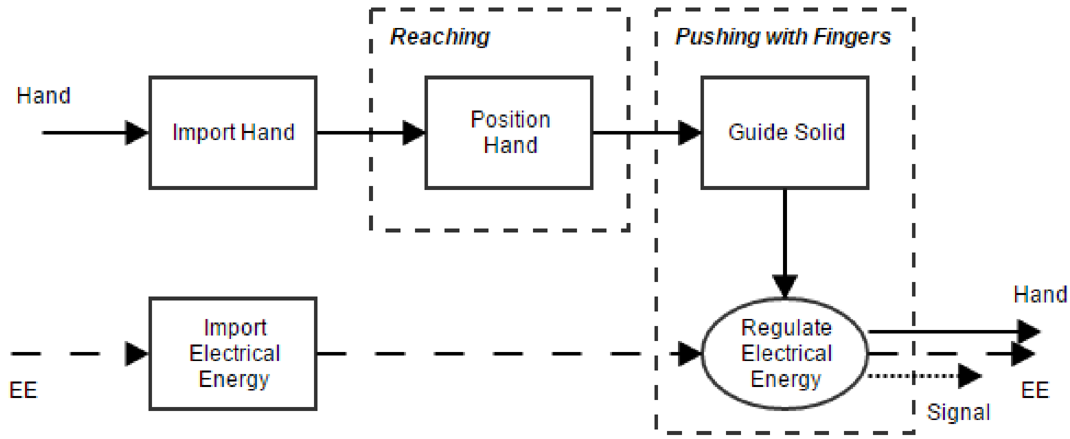
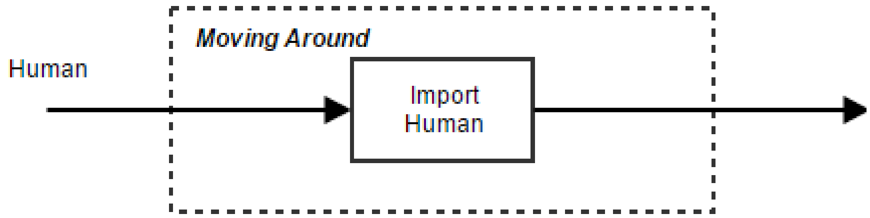


Figure 153. Modified Clothes Iron Actionfunction Diagram for Case 29

Users with hand impairments have difficulty gripping and physically turning turn switches. Sangelkar's relevant design rule suggests that parametric changes to the switch would lead to a more inclusive product. Parametric changes to the switch's length would give the user a mechanical advantage and allow them to turn the switch by applying force with their fingers. Redesigning the dimensions of the turn dial so users can turn the switch by pushing makes for a more inclusive method of actuating power in a product.

Case 30: Securing Users

Designers should consider users with diminished mobility when designing products and environments. In order to develop more inclusive products and environments, designers should consider adding in functions pertaining to securing the user as the user moves around. In this case we consider the basic actionfunction diagram of a user moving through a generalized environment. The actionfunction diagram and relevant rule are shown in Figure 154.



Rule Set	User Activity	Product Function	Recommended Change
Sangelkar	Moving Around	Secure Human	Functional

User Activity (ICF Term)	Meaning
Moving Around	Moving the whole body from one place to another

Figure 154. Actionfunction Diagram and Rule for Case 30: Securing users

Applying Sangelkar's design rule suggests a functional addition of a 'Secure Human' function to under the 'Moving Around' user activity. This functional addition represents the addition of system components that allow users secure and steady themselves as they move through the environment. The modified actionfunction diagram is shown in Figure 155.

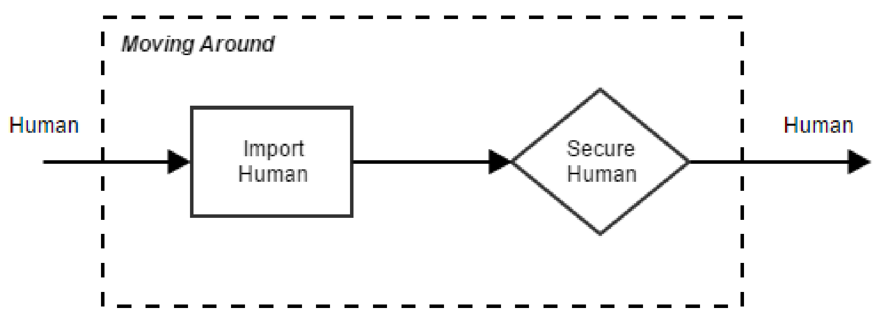
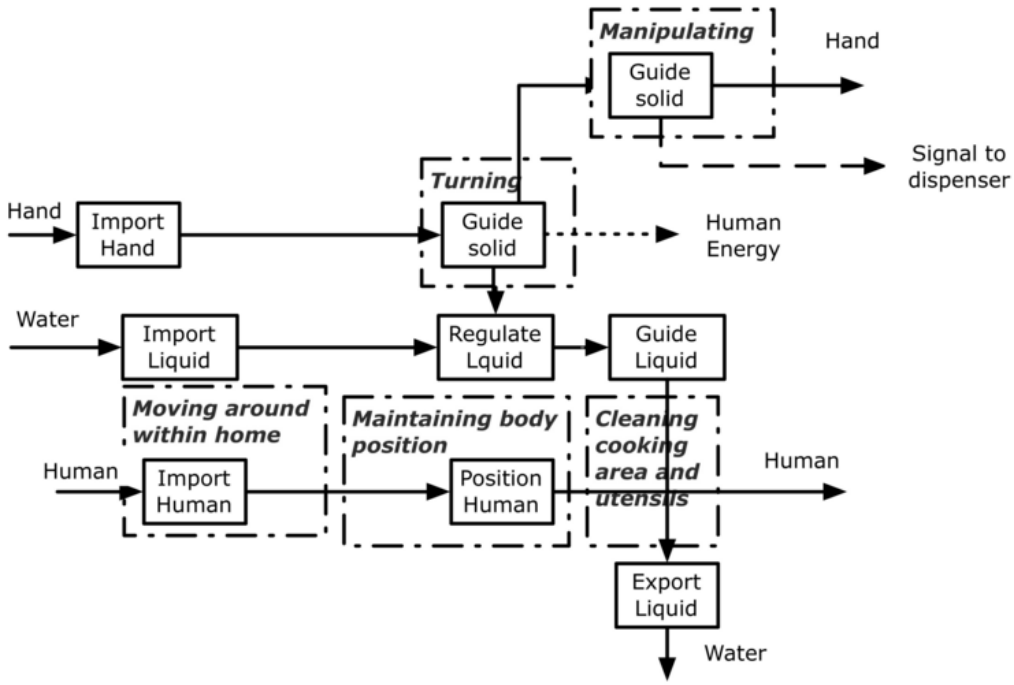


Figure 155. Modified Actionfunction Diagram for Case 30

The functional addition of the 'Secure Human' function can be accomplished a variety of ways. Designers could make the environment more inclusive by incorporating hand rails or walls for users to brace themselves on. Designers could also satisfy the functional addition of a 'Secure Human' by adding in seating areas or benches to allow uses to support themselves as they move through the environment.

Case 31: Kitchen Sink

Designers should consider users with diminished mobility when designing products and environments that require the user to maintain their body position while performing a certain task. In this case we consider the typical kitchen sink, particularly the functions pertaining to how a user maintains their body position while cleaning the dishes.



Rule Set	User Activity	Product Function	Recommended Change
Sangelkar	Maintain Body Position	Position Human	Parametric

User Activity (ICF Term)	Meaning
Maintain Body Position	Staying in the same body position as required, such as remaining seated or remaining standing for work or school.

Figure 156. Actionfunction Diagram and Rule for Case 31: Kitchen Sink

Applying the suggested design rule in this case yields a parametric change to the 'Position Human' function involved in the 'Maintain Body Position' user activity. This change suggests that modifying the parameters of the sink involved with position the user, such as height and width of the sink, would lead a more inclusive product. The modified actionfunction diagram is pictured in Figure 157.

The parametric changes suggested by Sangelkar's design rule would serve to make the

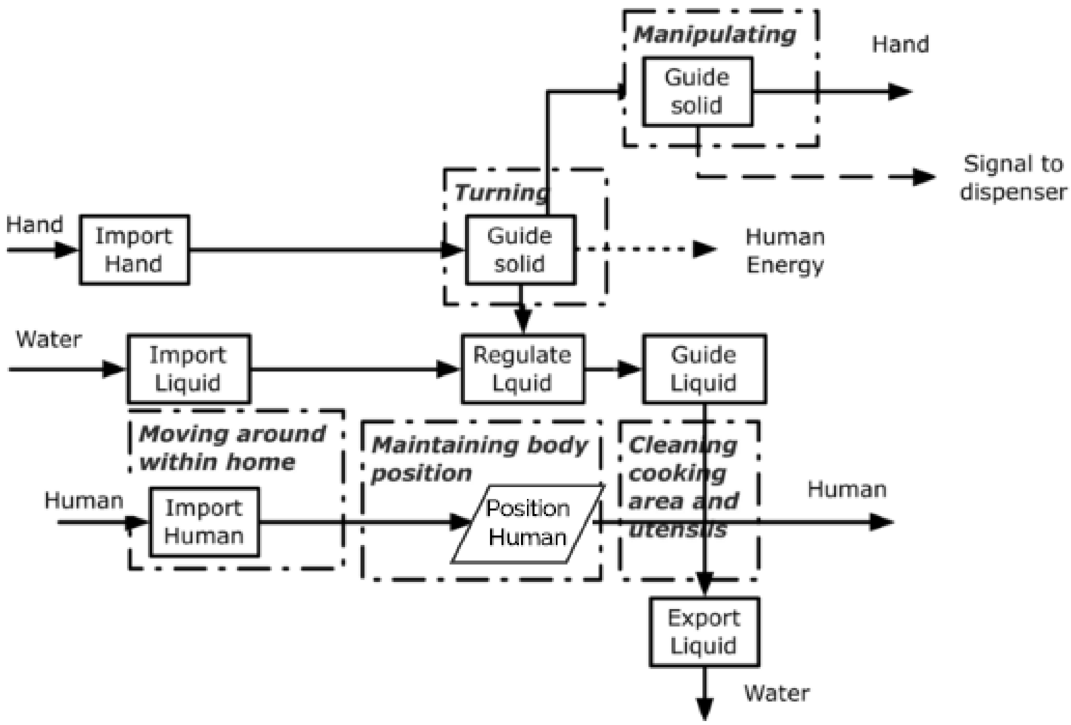
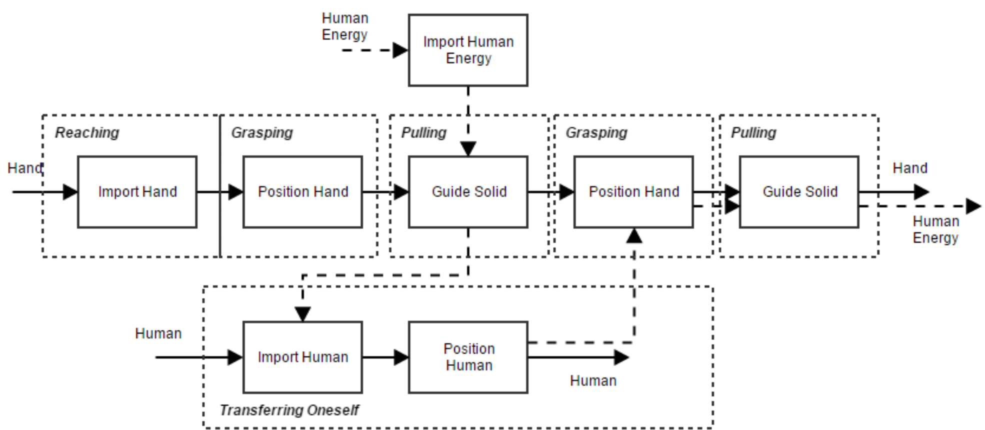


Figure 157. Modified Actionfunction Diagram for Case 31

kitchen sink more inclusive to all users. Lowering the sink height would open up the sink to more users, as it lowers the height requirements for use. Likewise, this design rule could lead designers to develop a more inclusive sink for mobility impaired users in wheelchairs or powered scooters by eliminating the cabinets under the sink to open up the below-sink area. Parametric changes such as these would lead to more inclusive user-product interactions in a kitchen sink.

Case 32: Car Door, Ramp-Rail System

Designers should consider users with diminished mobility when designing the access points for products and environments. Users with mobility impairments will have trouble transferring themselves into the car through the car door unassisted, as they may lack the coordination or strength necessary to pull themselves into the car. Figure 158 shows the actionfunction diagram of a typical car door and the associated design rule for Case 32.



Rule Set	User Activity	Product Function	Recommended Change
Sangelkar	Transferring Oneself	Import Human	Morphological

User Activity (ICF Term)	Meaning
Transferring Oneself	Moving from one surface to another, such as sliding along a bench or moving from a bed to a chair, without changing body position.

Figure 158. Actionfunction Diagram and Rule for Case 32: Car Door

In this case, the relevant design rule suggests that a morphological change to the 'Import Human' function under the 'Transferring Oneself' user activity would lead to a more inclusive car door. This change means that designers could develop a more accessible car door by changing the physical solution to how a user enters the car. Figure 159 shows the car actionfunction diagram as modified by the relevant design rule of Case 32.

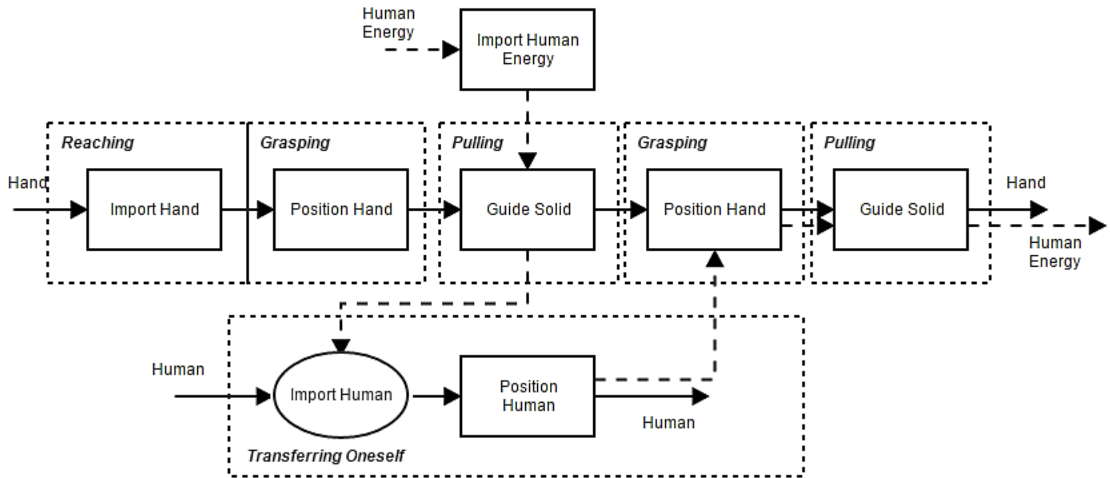


Figure 159. Modified Car Door with Morphological Change

There are many preexisting solutions to transferring disabled users into a car, such as hydraulic lifts or personal assistance; however, these systems generally require extensive modification to the car frame or physical exertion. A more universal solution would incorporate an inclusive method of transferring a mobility-impaired user into a car, while still being useful for typical, non-impaired users. Such a solution could include a sliding ramp on a mobile rail system that is incorporated into the car's frame. This sliding ramp solution is pictured in Figure 160. In the sliding ramp system, there are three rails that are housed in corresponding slots under the floorboards of the car. Likewise, there is a spring loaded spool that houses metal slats that make up the ramp floor. These slats have u-shaped clamps that lock onto the rails to secure the ramp. In order to deploy the ramp, the user first slides out the rails from their housing slots. These rails have heavy, rubber coated feet that secure the rails against the ground. The user then deploys the ramp by pulling the ramp slats from their spool and locking them into position. This system creates a ramp that allows users to walk up a gradual slop in order to seat themselves in the car. Users with mobility impairments will have a much easier time slowly walking up a ramp than they have stepping up into the car from the ground. This modification, brought about by the suggestion of a morphological change from Sangelkar's relevant design rule, leads to a more inclusive product with a much simpler solution than most current systems.

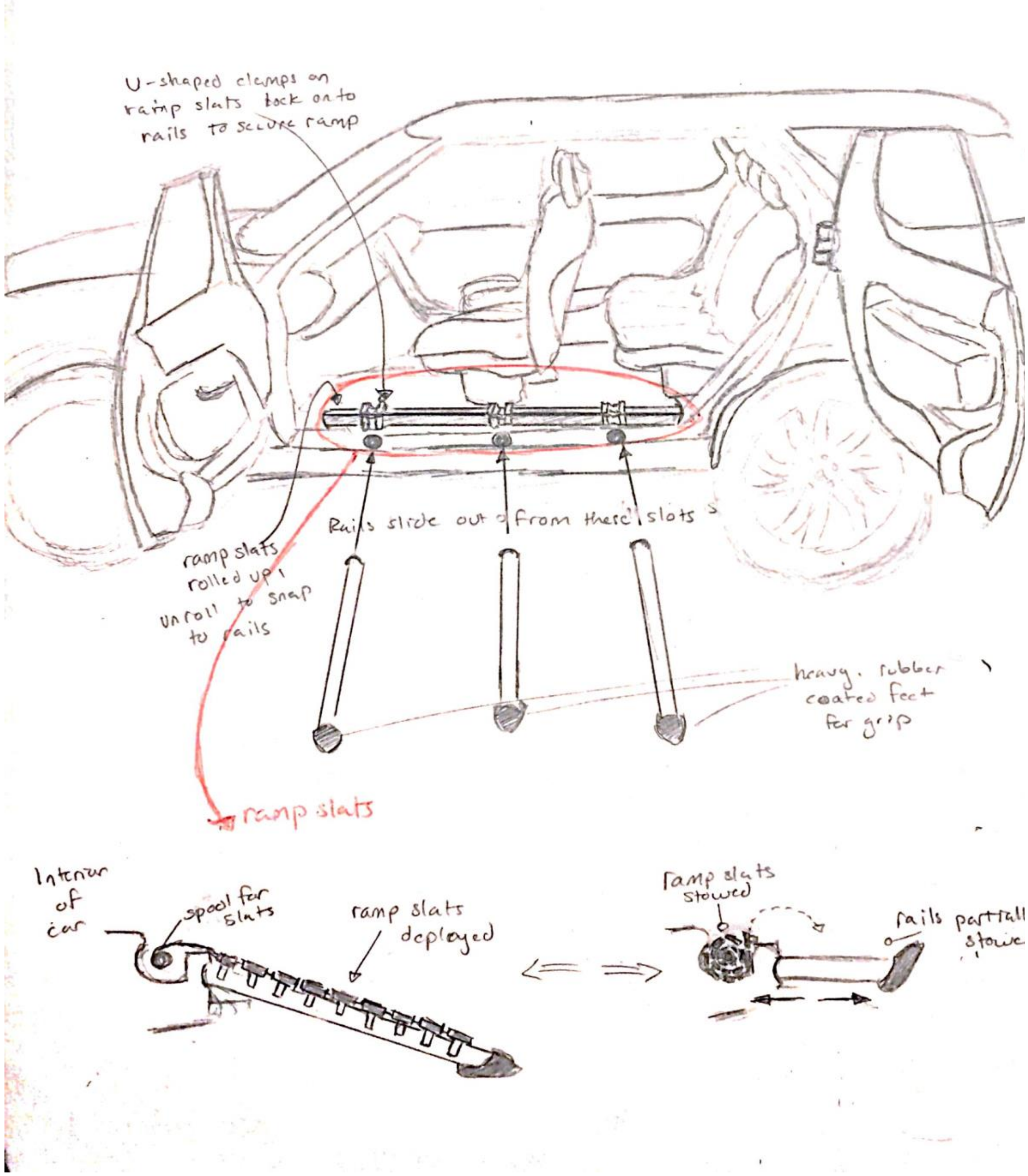
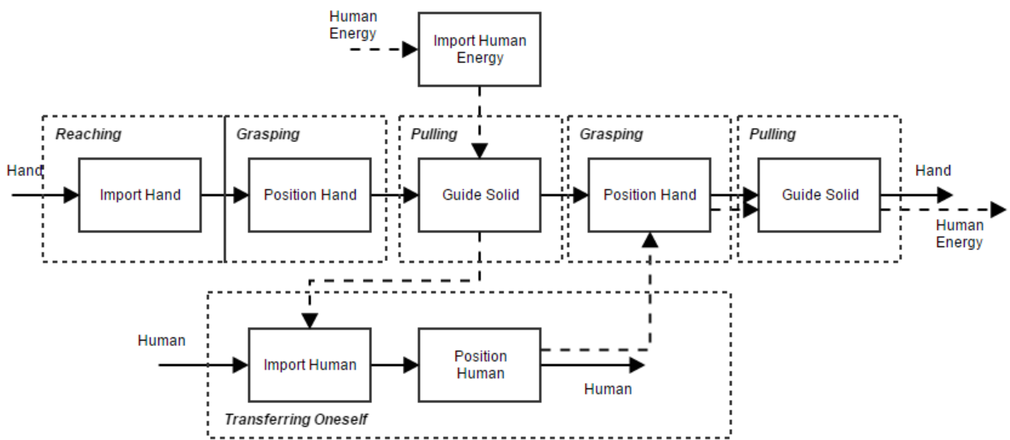


Figure 160. Modified Car Door, Ramp-Rail System

Case 33: Car Door, Door Parameters

When designing access points in products and environments, designers should consider users of all sizes and ability levels when setting the entryway parameters. Larger users, and users with forms of mobility assistance (walkers, wheelchairs, etc.) require larger entryways in order to enter the specified product or environment. In this case we again consider the doors on a typical car. The actionfunction diagram pertaining to how a user enters a car door is shown in Figure 161 alongside the relevant design rule.

Applying the relevant design rule in this case yields a parametric change to the 'Import



Rule Set	User Activity	Product Function	Recommended Change
Sangelkar	Transferring Oneself	Import Human	Parametric

User Activity (ICF Term)	Meaning
Transferring Oneself	Moving from one surface to another, such as sliding along a bench or moving from a bed to a chair, without changing body position.

Figure 161. Actionfunction Diagram and Rule for Case 33: Car Door

Human' function under the 'Transferring Oneself' user activity. This parametric change suggests to designers that modifying the parameters of the entryway would lead to a more accessible car door. The modified actionfunction diagram from applying this design rule is shown in Figure 162.

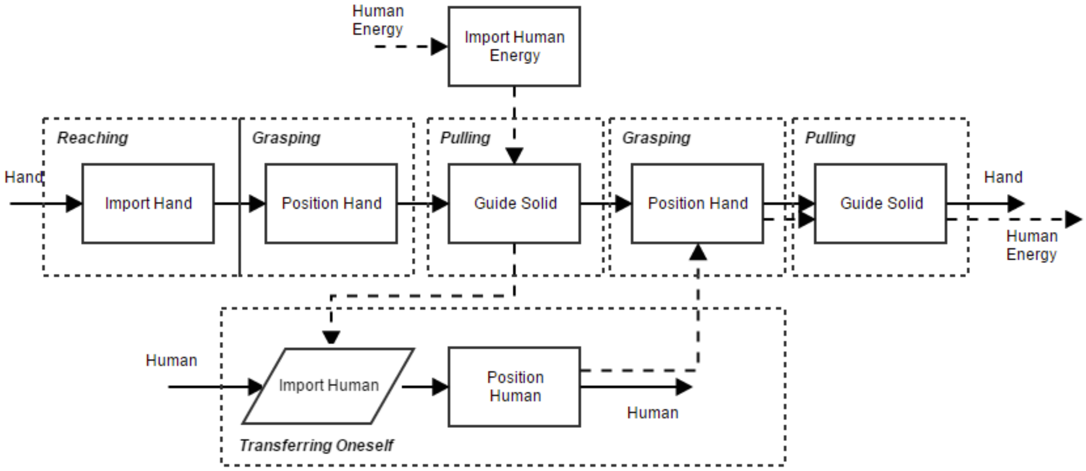


Figure 162. Modified Car Door Actionfunction Diagram with Parametric Change

The parametric change recommended by the design rule can be accomplished a variety of ways. Designers could lower the height of the car's floor in order to make the step up into the car easier for shorter users or for users with mobility impairments. Designers could also modify the width of the car door in order to provide more room for users to enter the system. In this case, we have accomplished the parametric change by adjusting how the rear door opens, in order to provide a very large opening for users to enter through. This modified car door can be seen in Figure 163.

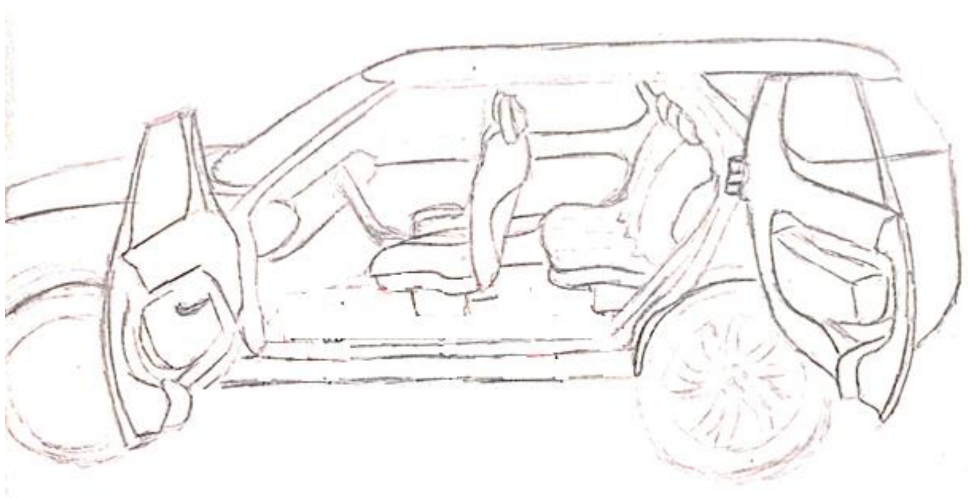
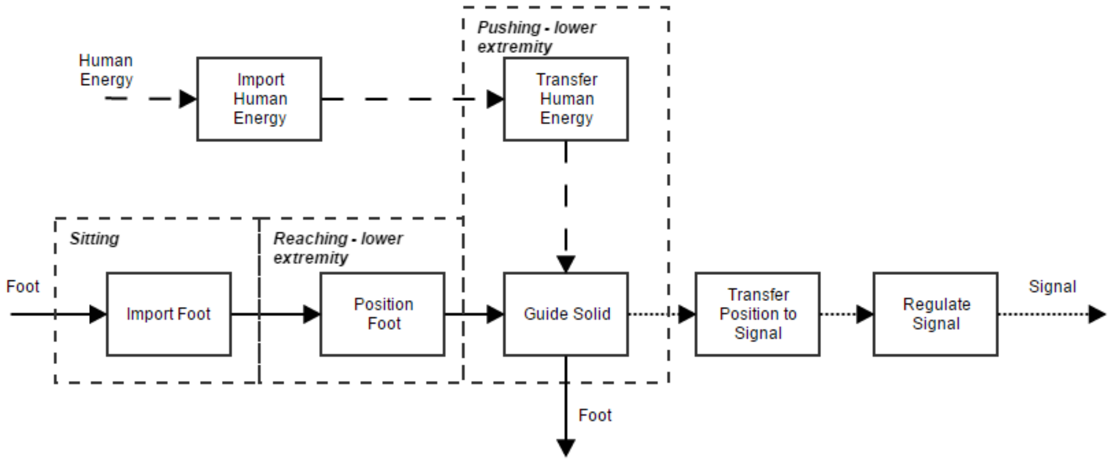


Figure 163. Modified Car Door with Parametric Change

Case 34: Gas Pedal

Designers should consider users with diminished lower body strength when designing products that need to be pushed with the lower extremities. Less abled users may not have the strength or lower body dexterity to push a product with their feet or legs. In this case we consider the actionfunction diagram of a car's gas pedal, for which the corresponding actionfunction diagram is pictured in Figure 164.



Rule Set	User Activity	Product Function	Recommended Change
Sangelkar	Pushing with Lower Extremities	Guide Solid	Morphological → Pushing with Hand

User Activity (ICF Term)	Meaning
Pushing with Lower Extremities	Using the legs and feet to exert a force on an object to move it away

Figure 164. Actionfunction Diagram and Rule for Case 34: Gas Pedal

Applying Sangelkar's design rule in this case yields a morphological change to the 'Guide Solid' function under the 'Pushing – lower extremity' user activity. This change signifies to the designer that, in order to account for lower body disabilities, the designer needs to modify the gas pedal in such a way that all functions can be accomplished by the user using their upper body rather than their lower body. The modified actionfunction diagram obtained from applying this design rule is shown in Figure 165.

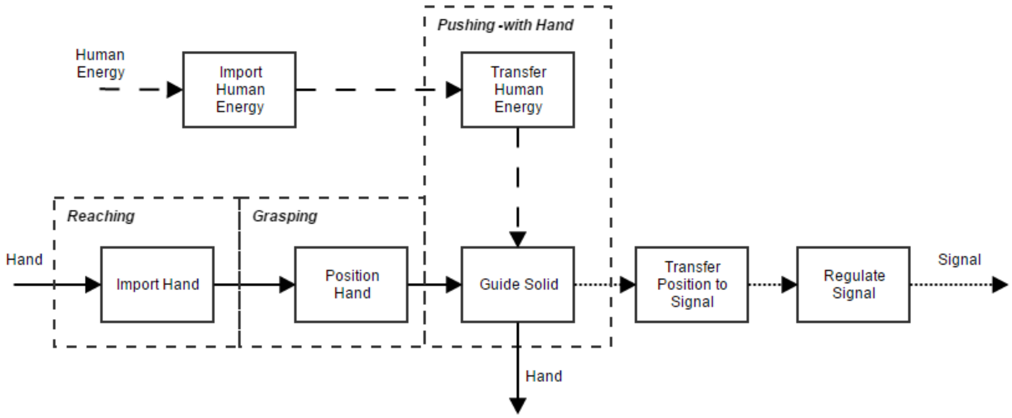


Figure 165. Modified Gas Pedal Actionfunction Diagram

This modified actionfunction diagram can be represented by a joystick system for accelerating and decelerating a car. Instead of using their feet to push a pedal, users can instead position a joystick, or pull a specific trigger on said joystick to trigger the accelerator and brake systems of the car. These modifications, suggested by the application of Sangelkar's design rule, would allow users, who would previously be unable to drive due to lower body disabilities, to operate a car's accelerator and brake systems.

APPENDIX E: EXPERIMENTAL SURVEY QUESTIONS

Product Redesigns – Application of Inclusive Design Rules

Description of Survey:

The purpose of this survey is to gauge the effectiveness of inclusive design rules on a rule-by-rule basis. The sketches in this survey depict products that have been redesigned using design rules that have been mined from human capability design guidelines and analysis of pairs of inclusive and typical products. These introductory sections explain the background work for, and purpose of, this survey.

Universal (or Inclusive) Design:

Universal design is the engineering practice to develop products and environments in such a way that they can be used effectively by all users, regardless of their ability level. Researchers also refer to universal design as accessible design, design for disability, or inclusive design. Universal design can be practiced on any product or environment. In order to best design a product for universal use, one must consider the demands on a user's capabilities. Any user who cannot meet the capabilities demanded by a certain product is severely limited in, if not excluded entirely from, its use. In order to include the widest possible range of users, designers should develop products with user capabilities in mind.

Inclusive Design Rules:

Research into the field of inclusive design has yielded a form of design rule, that when applied to a functional model of a product, results in suggested changes that would make the product more inclusive. These design rules have been developed by analyzing the relationships between typical (or non-inclusive) products and their inclusive counterparts. Additionally, more design rules can be added to this set by translating design guidelines from different formats into the design rule format. The purpose of this survey is to test the results of applying these design rules

Format of Survey:

In order to test the effectiveness of inclusive design rules, we have developed a survey form. For the purpose of this explanation, the persons taking this survey will be referred to as *participants*. In this survey, the participants will be given a number of sketches of products that have been modified using the aforementioned design rules. Each modified product will be accompanied by an explanation of what the product is, what type of disability was being considered, what design rule was applied, and what changes have been made to make the product more inclusive. For each modified product, the participants will be given a survey questionnaire that will ask questions on the modified products. These questions will attempt to determine the effectiveness of the related design rules by gauging how the tester perceives the inclusivity of the resulting product.

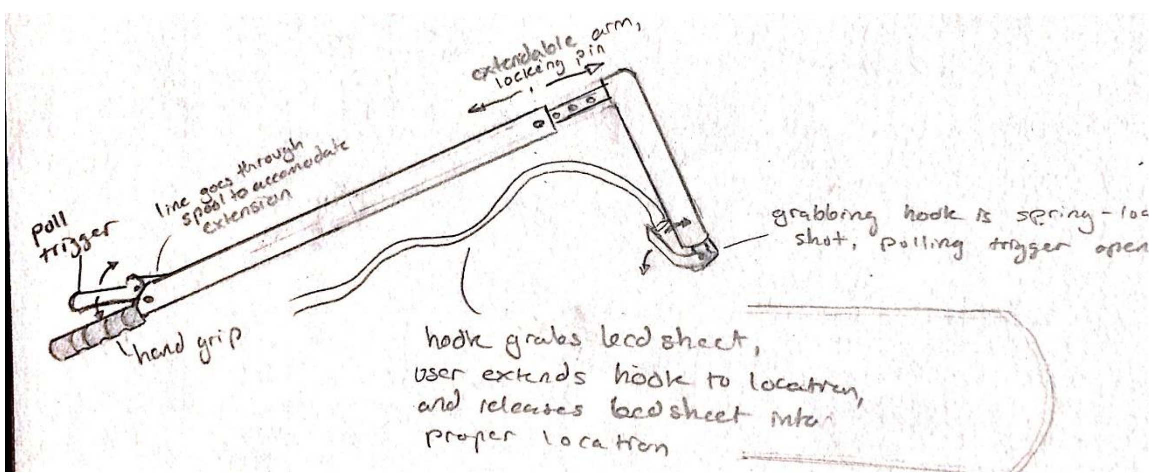
The modified products, their descriptions, and descriptive images begin on the next page. The questions are split up into four groups, so as to split up the survey into manageable groups of questions for each participant.

GROUP ONE

Case 1: Fitted Bed Sheet

Users with diminished hand strength or dexterity, either due to age or injury, have trouble grasping products. Because they lack the necessary hand strength, users with impairments of the hand may not be able to maintain their grip on certain products as the user operates the product. Applying the relevant design rule yields the following two modified methods of installing a bed sheet.

One design rule suggests designing a new physical solution to how the user changes the sheet. In this case we have developed a special gripping arm. The gripping arm has a hook that grabs the sheets and allows the user to extend the grip arm to the proper location to secure the sheet. This grip arm is extendable, in order to allow users to reach the sheet without having to grip the sheets with their hands. A trigger assembly on the handle of the gripping arm allows users to disengage the hook and secure the sheet once it is in the proper location.



Representation of Bed Sheet Gripping Arm

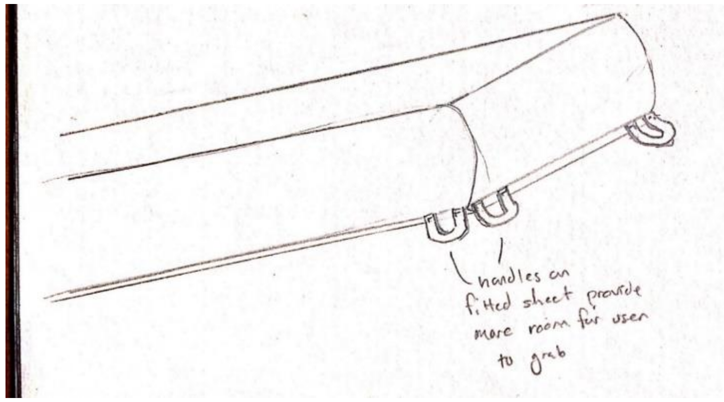
Questionnaire on Case 1: PART ONE: Bed Sheet Gripping Arm

The following questionnaire serves to gauge the tester's opinions on the inclusivity of the newly modified fitted sheet gripping arm. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how this product functions	○	○	○	○	○
2. Overall I think this product would be easy to use.	○	○	○	○	○
3. I can understand how this product addresses users with disabilities	○	○	○	○	○
4. I think this product will increase disabled users' productivity.	○	○	○	○	○
5. I think this product would make disabled users' jobs easier.	○	○	○	○	○
6. Overall, I think this product would be useful for users with disabilities	○	○	○	○	○
7. Overall, I think this product would be useful for users without disabilities	○	○	○	○	○
Additional Comments/Feedback:					

The other design rule suggests changes that lead to adding handles to the fitted bed sheets. In order to provide more area for the user to grab ahold of, we have chosen to design in special handholds on the fitted sheet. These cloth handles would provide more room for the user

to grip, and would be easier to securely grasp than the thin edges of a sheet. A physical embodiment of this proposed change is sketched out in the next figure.



Representation of Fitted Sheet with Handles

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how this product functions	○	○	○	○	○
2. Overall I think this product would be easy to use.	○	○	○	○	○
3. I can understand how this product addresses users with disabilities	○	○	○	○	○
4. I think this product will increase disabled users' productivity.	○	○	○	○	○
5. I think this product would make disabled users' jobs easier.	○	○	○	○	○
6. Overall, I think this product would be useful for users with disabilities	○	○	○	○	○
7. Overall, I think this product would be useful for users without disabilities	○	○	○	○	○
Additional Comments/Feedback:					

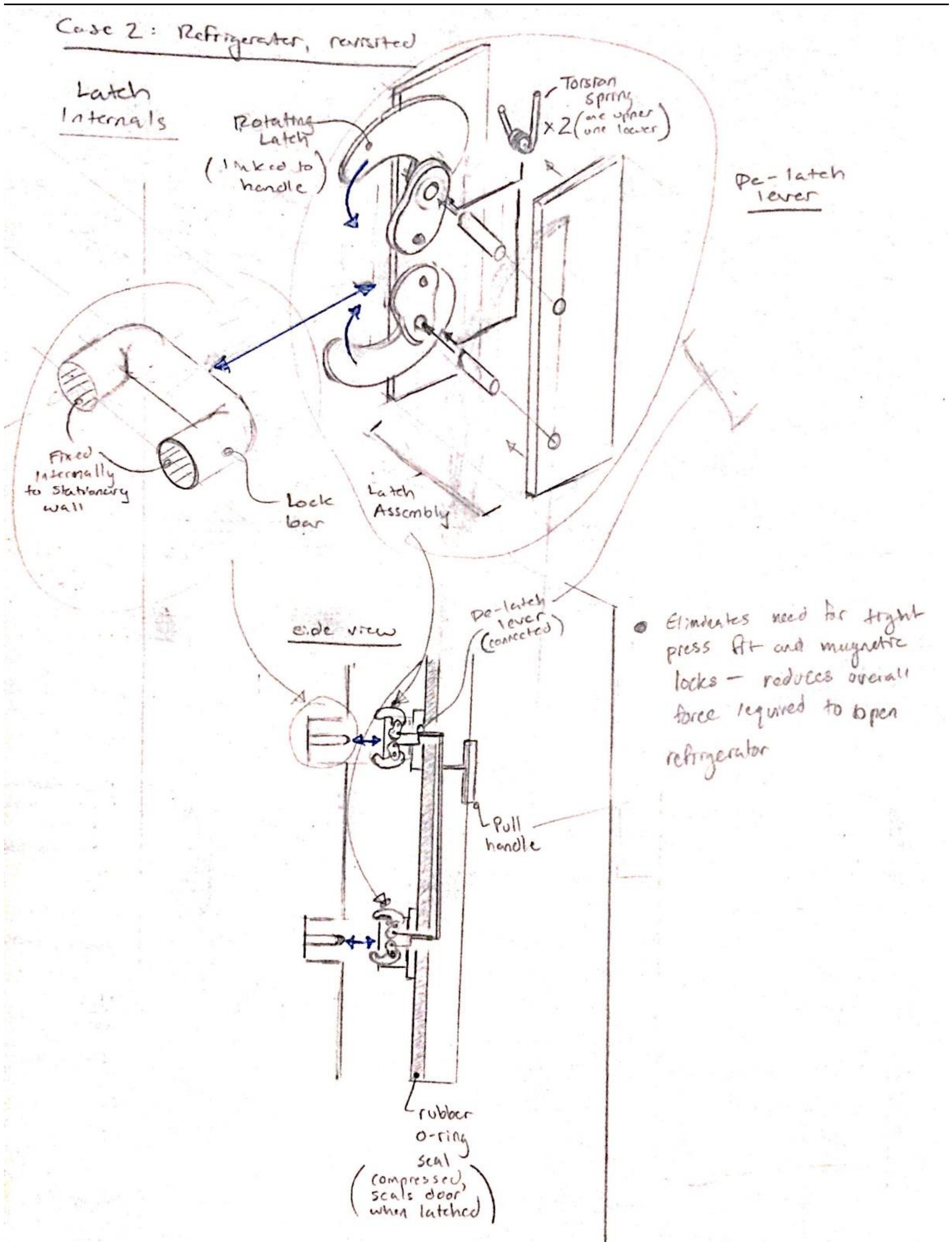
<u>Questionnaire on Case 1: PART TWO – Fitted Sheet Handle:</u>

The following questionnaire serves to gauge the tester's opinions on the inclusivity of the newly modified <u>fitted sheet with handles</u>. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

Case 2: Refrigerator Door Latch

Users with diminished strength may find the force requirements too high for breaking the seal and opening the refrigerator door. Refrigerator door seals are generally tight due to magnetic strips as well as the pressure differential between the cool air inside and the warm air outside. While users may still be able to open the door through considerable application of their force, it could be beneficial for designers to develop a more easy to open refrigerator for persons suffering from arthritis, injuries, or other debilitating conditions.

Applying the relevant design guidelines yields a functional addition in order to assist users in opening the refrigerator door This functional addition is meant to represent the addition of features to create a mechanical advantage for the user so that they will able to open the door with less force. For the purpose of this case study, we have chosen to develop a special type of latch affixed to the refrigerator door that would eliminate the need for a tight seal and magnetic locks. A physical embodiment of this solution is sketched out in the next figure. A latch would connect to a lever that is in turn connected to a seals in the door. When the latch is pulled, the lever is actuated and pulls the seals, thereby releasing the locks on the refrigerator door and allowing the door to freely swing open.



Representation of Refrigerator Latch Lock

Questionnaire on Case 2: Refrigerator Door Latch

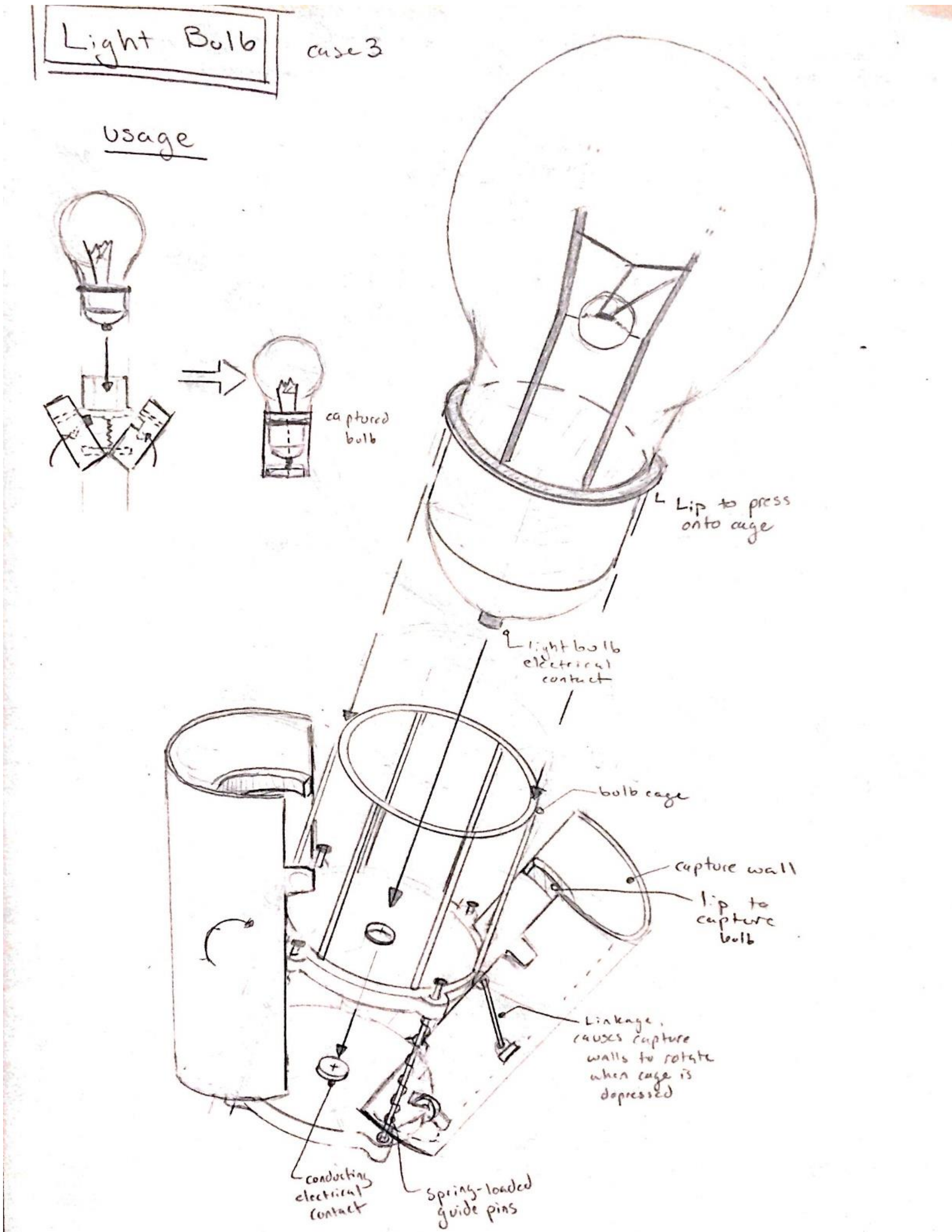
The following questionnaire serves to gauge the tester's opinions on the inclusivity of the newly modified refrigerator door latch. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how this product functions	○	○	○	○	○
2. Overall I think this product would be easy to use.	○	○	○	○	○
3. I can understand how this product addresses users with disabilities	○	○	○	○	○
4. I think this product will increase disabled users' productivity.	○	○	○	○	○
5. I think this product would make disabled users' jobs easier.	○	○	○	○	○
6. Overall, I think this product would be useful for users with disabilities	○	○	○	○	○
7. Overall, I think this product would be useful for users without disabilities	○	○	○	○	○
Additional Comments/Feedback:					

Case 3: Light Bulb

Users with diminished hand strength may have difficulties performing activities that require simultaneous manipulations. A product that requires simultaneous manipulations is a lightbulb, as users must push and turn the lightbulb in order to install it. Typical lightbulbs are installed by pushing and twisting the bulb into a threaded socket, which would be a difficult set of actions to perform for someone with some form of hand impairment. Applying the relevant design rule yields the following, modified, product. In order to make installing a light bulb more inclusive for users who have difficulty performing simultaneous manipulations, we must develop a new method to install and uninstall a lightbulb.

A physical embodiment of this solution is sketched out on the next page. This new method utilizes a special rotating latch mounted to a cage where the bulb sits. To install the light bulb, a user simply needs to push the bulb into the cage until it contacts the electrical contacts. The user continues pushing the bulb after the bulb contacts the electrical contact, thereby depressing the whole bulb-cage assembly. As the bulb-cage assembly is pushed down, it rotates two locking gears that are attached to two capture walls. When the bulb-cage assembly is fully depressed, these two capture walls fully enclose the base of the bulb, and the locking gears lock into position, thereby securing the whole assembly. To uninstall the bulb, a user needs to gently press in on a tab on the side, which releases the locking capture walls, after which the user can simply pull the bulb out of the socket.



Representation of Modified Lightbulb

Questionnaire on Case 3: Light Bulb

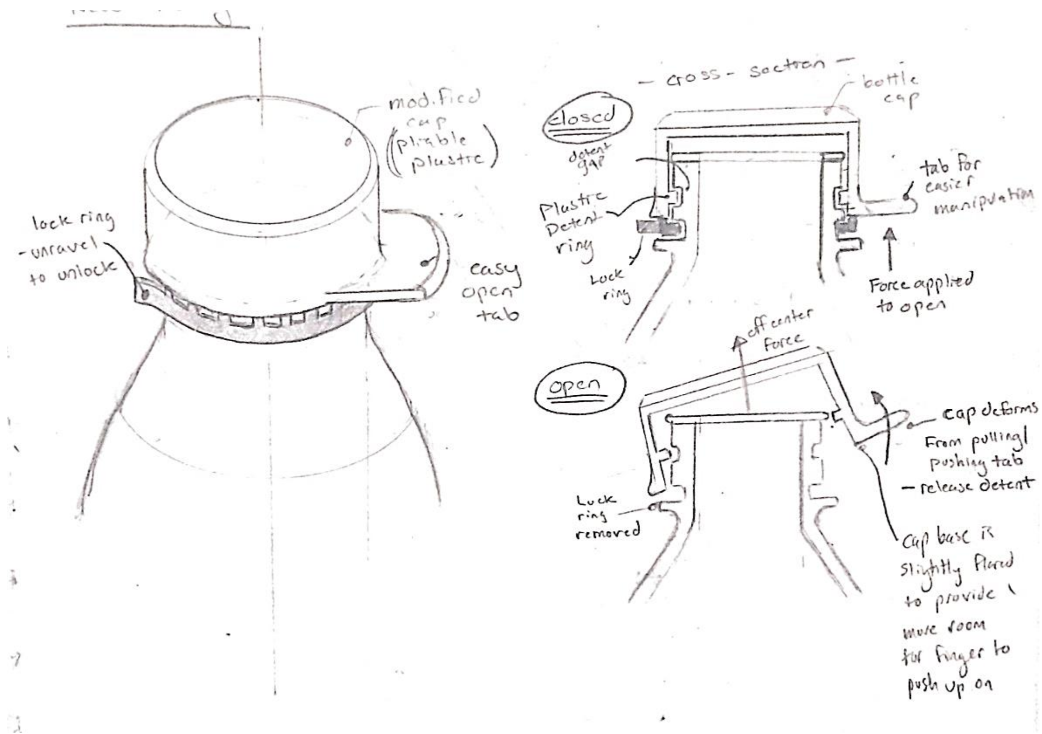
The following questionnaire serves to gauge the tester's opinions on the inclusivity of the newly modified light bulb. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how this product functions	○	○	○	○	○
2. Overall I think this product would be easy to use.	○	○	○	○	○
3. I can understand how this product addresses users with disabilities	○	○	○	○	○
4. I think this product will increase disabled users' productivity.	○	○	○	○	○
5. I think this product would make disabled users' jobs easier.	○	○	○	○	○
6. Overall, I think this product would be useful for users with disabilities	○	○	○	○	○
7. Overall, I think this product would be useful for users without disabilities	○	○	○	○	○
Additional Comments/Feedback:					

Case 4: Bottle Cap

Users with diminished dexterity may have difficulties utilizing a pincer grip to grasp objects, as is necessary when turning an object. Designers should consider modifying products that require turning to instead utilize a different user activity. A classic example of a product that requires gripping and turning is a twist-off bottle cap, such as one would find on a plastic water bottle. When applied to the bottle cap, this rule leads to a morphological change of how the bottle cap is attached to and removed from the bottle. Typical bottle caps are threaded onto a receiving thread on the bottle, a cheap and reusable way of sealing the bottle. In developing a more inclusive product, we must also consider the marketability of the resulting product. Current bottle caps are utilized due to their simplicity and low cost, so any new inclusive design should not unduly increase the cost or complexity of the system. A proposed redesign of the typical bottle cap is shown in the next figure.

This new design utilizes a detent feature on the inside of the bottle cap that fits into a groove in the mouth of the water bottle. To remove the bottle cap, the user pushes or pulls up on the bottle cap. Because the cap is made of a pliable plastic, the cap will elastically deform and thus clear the detent feature and release from the bottle. This detent feature, and the corresponding pushing and pulling manipulations, accounts for the morphological change to the ‘Guide Solid’ function. In order to avoid the bottle caps being accidentally deformed and opening the bottles, as may happen during the bumps and shocks involved in shipping, we have also added in a perforated plastic locking ring, which accounts for the ‘Release Solid’ functional addition. In order to release the bottle cap so that it may be opened, a user must first pull a tab on the locking ring and unravel it from the bottle cap. The newly modified bottle cap design can still be easily manufactured from the same materials and processes as the original twist-off bottle cap, and thus does not lead to a less marketable product.



Representation of Modified Bottle Cap

<u>Questionnaire on Case 4: Bottle Cap</u>

The following questionnaire serves to gauge the tester's opinions on the inclusivity of the newly modified bottle cap. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how this product functions	○	○	○	○	○
2. Overall I think this product would be easy to use.	○	○	○	○	○
3. I can understand how this product addresses users with disabilities	○	○	○	○	○
4. I think this product will increase disabled users' productivity.	○	○	○	○	○
5. I think this product would make disabled users' jobs easier.	○	○	○	○	○
6. Overall, I think this product would be useful for users with disabilities	○	○	○	○	○
7. Overall, I think this product would be useful for users without disabilities	○	○	○	○	○
Additional Comments/Feedback:					

Case 9: Entry and Exit

In order to make products and environments more inclusive, designers should set entry and exit dimensions large enough to provide adequate space for all potential users. Designers should consider users' locomotive aids, such as walkers and wheelchairs, when setting these dimensions so as to not exclude any potential users. Applying a relevant design rule results in parametric changes to the door. These parametric changes could include changes to the height or width of the door entryway. Increasing the doorway dimensions would lead to a more inclusive product, and would allow users of all dimensions (be they physically impaired or not)

Questionnaire on Case 9: Entry and Exit

Please answer the following questions to the best of your ability:

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how these changes would be implemented	○	○	○	○	○
2. I can understand how these changes address users with disabilities.	○	○	○	○	○
3. Overall, I think these changes would be useful for users with disabilities.	○	○	○	○	○
4. Overall, I think these changes would be useful for users without disabilities.	○	○	○	○	○
Additional comments/feedback					

Case 10: Supports

In order to design more inclusive environments and to assist less abled users, designers should consider providing adequate seating and resting areas at regular intervals. Physically impaired users may have difficulty moving through an environment without rest, and may require seating areas to support themselves as they move through the environment.

<u>Questionnaire on Case 10: Supports</u>

Please answer the following question to the best of your ability:

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how these changes would be implemented	◯	◯	◯	◯	◯
2. I can understand how these changes address users with disabilities.	◯	◯	◯	◯	◯
3. Overall, I think these changes would be useful for users with disabilities.	◯	◯	◯	◯	◯
4. Overall, I think these changes would be useful for users without disabilities.	◯	◯	◯	◯	◯
Additional comments/feedback					

Case 14: Interfacing with a Product

In order to make products and environments more inclusive, designers should ensure that the product areas the user interacts with, and the correct way to interact with them, are obvious to the user. Many products exclude users, regardless of their level of ability, by requiring unintuitive methods of user interaction. Control panels are typical products that require the user to develop a correct mental model of how the controls will affect the product.

The changes suggested by the relevant design rule include alterations to how a product conveys information to users. In order to develop more inclusive products, designers should choose solutions that lead to more intuitive products. Products could utilize alternative forms of communications, such as braille, color-coding, or informative symbols, in order to develop more intuitive, and thus more inclusive, products.

<u>Questionnaire on Case 14</u>

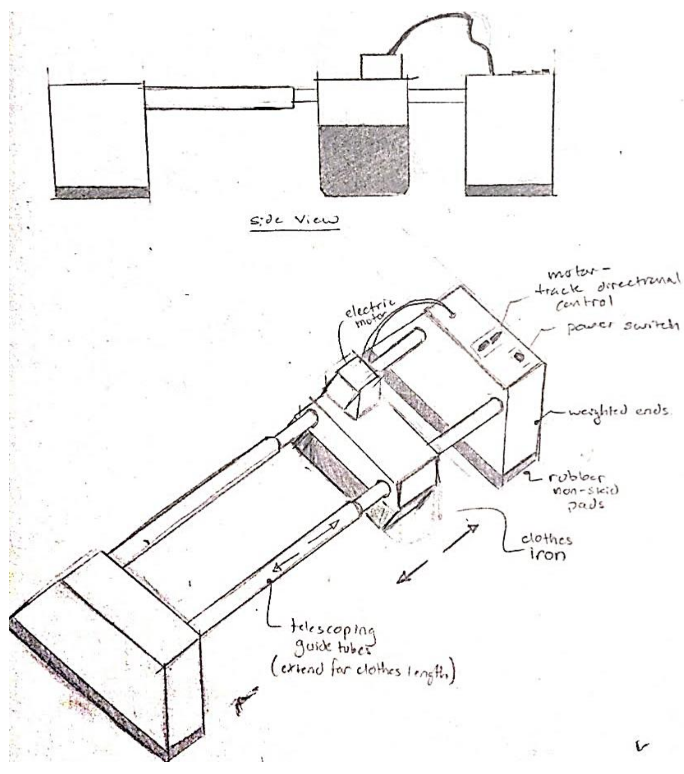
The following questionnaire serves to gauge the tester's opinions on the inclusivity of the newly modified control panel. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how these changes would be implemented	○	○	○	○	○
2. I can understand how these changes address users with disabilities.	○	○	○	○	○
3. Overall, I think these changes would be useful for users with disabilities.	○	○	○	○	○
4. Overall, I think these changes would be useful for users without disabilities.	○	○	○	○	○
Additional comments/feedback					

Case 28: Automatic Clothes Iron

Designers should consider users with upper body disabilities, or otherwise reduced upper body strength, when developing products that require the user to pull and guide some portion of the product. By enacting some physical change, designers can alter the product so that the moving parts are no longer associated with a user activity, and are instead accomplished by the product itself. In this case, we consider the typical clothes iron, for which the relevant design rule suggests implementing a physical change to how the user guides and moves the iron.

In this case, we have decided to implement an electrically powered iron to eliminate the need for users to physically guide the iron. This new method of moving the iron leads to the addition of an electrical motor and guiding controls. The modified automatic clothes iron is pictured in the next figure. This new product utilizes a heated ironing surface attached to a motor mounted on extendable rails. To stabilize the whole system, these rails are connected to two heavy end blocks with non-skid rubber feet. The user operates this automatic clothes iron by first extending the rails to the proper position to fully cover the clothes they are ironing. The user then actuates the power switch to power the iron's heating elements, after which the user can guide the automatic ironing head by using the two corresponding arrow shaped switches.



Modified, Automatic Iron

Questionnaire on Case 28: Automatic Clothes Iron

The following questionnaire serves to gauge the tester's opinions on the inclusivity of the newly clothes iron. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how this product functions	○	○	○	○	○
2. Overall I think this product would be easy to use.	○	○	○	○	○
3. I can understand how this product addresses users with disabilities	○	○	○	○	○
4. I think this product will increase disabled users' productivity.	○	○	○	○	○
5. I think this product would make disabled users' jobs easier.	○	○	○	○	○
6. Overall, I think this product would be useful for users with disabilities	○	○	○	○	○
7. Overall, I think this product would be useful for users without disabilities	○	○	○	○	○
Additional Comments/Feedback:					

GROUP TWO

Case 5: Rubber Coatings

Users with diminished dexterity have difficulties firmly grasping products. Users may experience reduced dexterity due to a large number of factors including increased age, illnesses, or disabilities. Users with reduced dexterity will have trouble firmly grasping products that are too thin, or that have smooth or slippery surfaces. Coating these surfaces with a material that increases friction, such as a rubber grip, could allow users to more securely grip such products. For example, coating portions of a syringe could allow users to more securely grasp the syringe when injecting insulin; or coating a door handle with a rubberized coating could allow users to get a firmer grip when turning the handle.

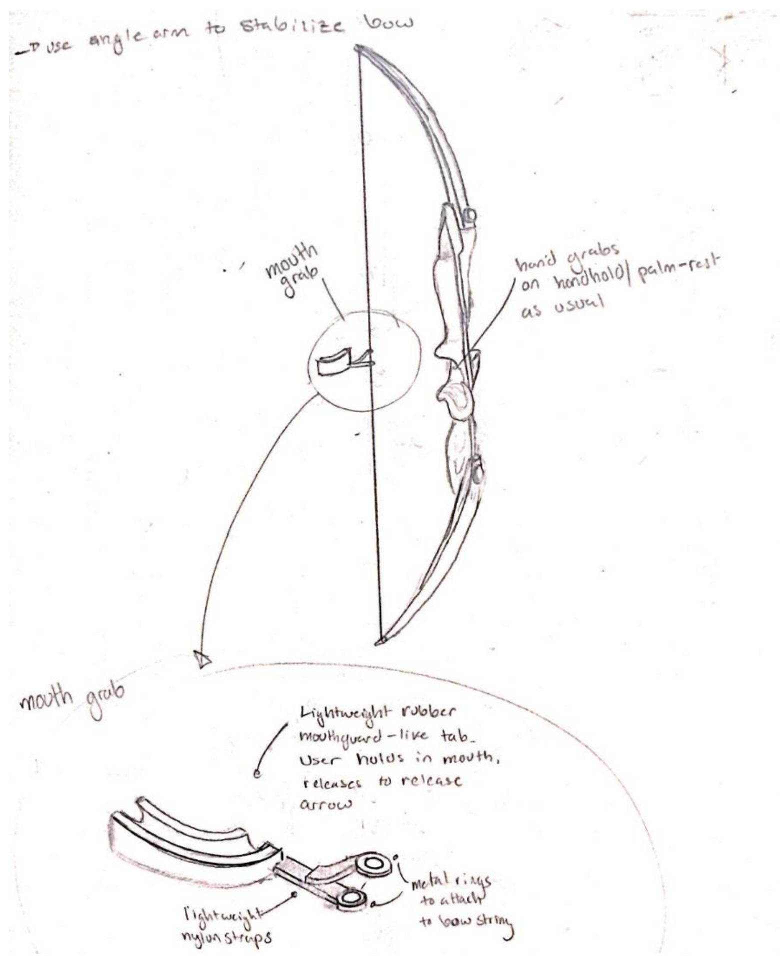
Questionnaire on Case 5: Rubber Coatings

The following questionnaire serves to gauge the tester's opinions on the inclusivity of the newly modified bow. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how this product functions	○	○	○	○	○
2. Overall I think this product would be easy to use.	○	○	○	○	○
3. I can understand how this product addresses users with disabilities	○	○	○	○	○
4. I think this product will increase disabled users' productivity.	○	○	○	○	○
5. I think this product would make disabled users' jobs easier.	○	○	○	○	○
6. Overall, I think this product would be useful for users with disabilities	○	○	○	○	○
7. Overall, I think this product would be useful for users without disabilities	○	○	○	○	○
Additional Comments/Feedback:					

Case 6: Bow with Mouth Grab

In order to design more inclusive products, designers should allow for users to operate their products with a single hand, rather than two. Users who may be missing limbs or who have arm injuries would be unable to operate products requiring two hands or arms for operation. Users with injuries, who previously enjoyed archery, would be unable to operate a bow normally without some modification. A bow is not typically associated with disabled use, however archery is a sport many enjoy. The relevant design rule suggest a change to the bow in order to allow for operation to be accomplished using a single arm. For the purpose of this case, this is accomplished by adding in the functionality for the user to somehow hold the bow string (normally accomplished using the dominant hand) in their mouth. A sketch of this new system is shown in the next figure.



Representation of Modified Bow with Mouth Grab

In this new design, a user would grasp the bow's handguard normally with one hand, while holding the bowstring using their mouth. A specially designed mouth grab allows the user to bite into a pliable rubber mouth guard attached to the bowstring. To draw the bow, the user would hold the bowstring (with a nocked arrow) using the mouth grab and extend the arm (holding the bow's handguard) forwards.

Questionnaire on Case 6: Bow with Mouth Grab

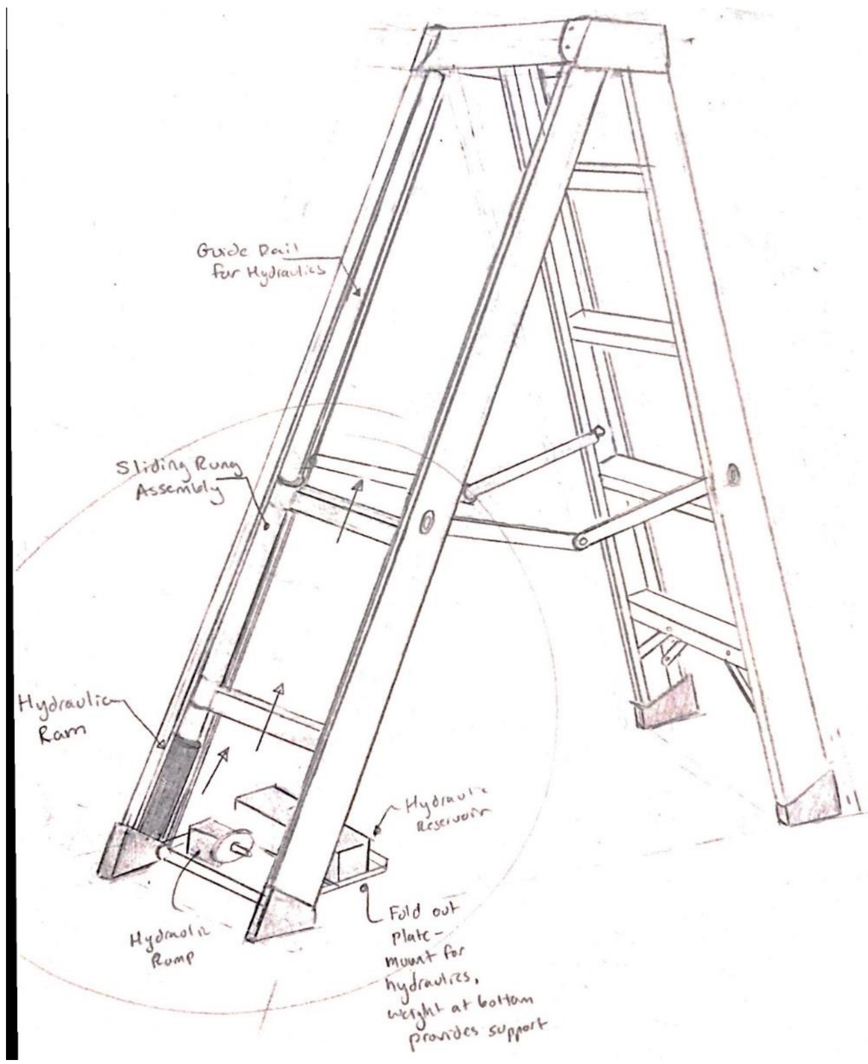
The following questionnaire serves to gauge the tester's opinions on the inclusivity of the newly modified bow. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how this product functions	○	○	○	○	○
2. Overall I think this product would be easy to use.	○	○	○	○	○
3. I can understand how this product addresses users with disabilities	○	○	○	○	○
4. I think this product will increase disabled users' productivity.	○	○	○	○	○
5. I think this product would make disabled users' jobs easier.	○	○	○	○	○
6. Overall, I think this product would be useful for users with disabilities	○	○	○	○	○
7. Overall, I think this product would be useful for users without disabilities	○	○	○	○	○
Additional Comments/Feedback:					

Case 7: Ladder

Users with physical impairments have reduced reach when compared to able users. Consider the typical ladder, in which a less able user would have difficulty reaching their hands or arms to guide themselves up the ladder.

The relevant design rule suggest a changes that modify the ladder to reduce the reach required to operate the ladder. In this case, we accomplish these changes by incorporating a hydraulic or pneumatic lift system. Now, instead of users having to reach for each ladder rung, they only have to reach for the first set of rungs. Once the user is on the first set of rungs, they can utilize the hydraulic or pneumatic pump to raise or lower the platform.



Representation of Modified Ladder

Questionnaire on Case 7: Ladder

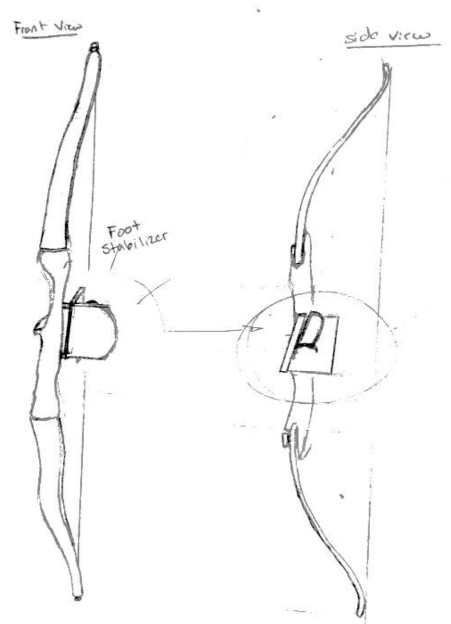
The following questionnaire serves to gauge the tester's opinions on the inclusivity of the newly ladder. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how this product functions	○	○	○	○	○
2. Overall I think this product would be easy to use.	○	○	○	○	○
3. I can understand how this product addresses users with disabilities	○	○	○	○	○
4. I think this product will increase disabled users' productivity.	○	○	○	○	○
5. I think this product would make disabled users' jobs easier.	○	○	○	○	○
6. Overall, I think this product would be useful for users with disabilities	○	○	○	○	○
7. Overall, I think this product would be useful for users without disabilities	○	○	○	○	○
Additional Comments/Feedback:					

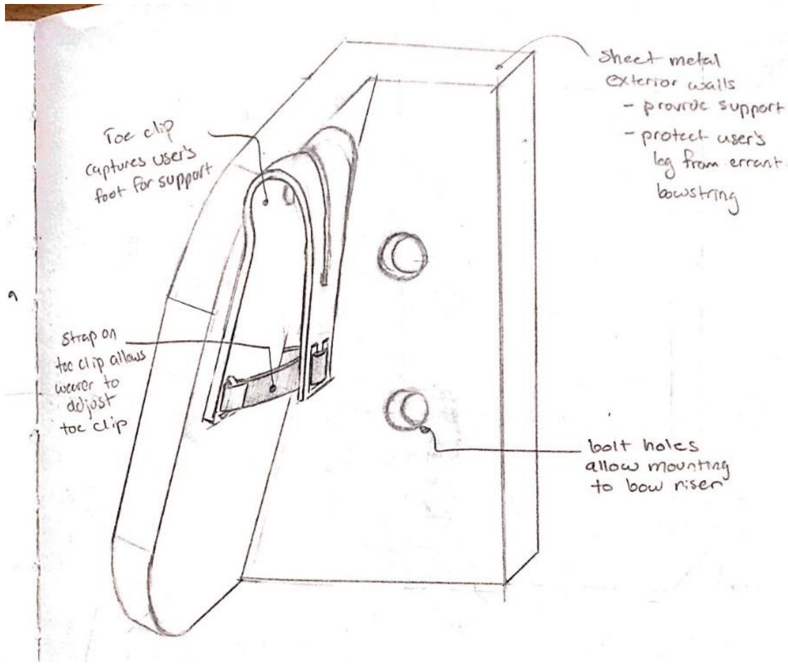
Case 8: Bow, Revisited

Users with physical impairments have difficulty exerting force with their arms outstretched. Consider the typical bow. While not typically associated with disabled users, archery is a sport many enjoy. Less able users would have difficulty drawing and steadying a typical bow, as they may not be strong enough to exert force with an outstretched arm. Designers should consider redesigning products such as a typical bow in such a way that users could operate the new products without exerting too much force with outstretched arms.

Applying the relevant design rule in this case changes how a user physically holds the bow and draws the bowstring back. In this case, we have accomplished these modifications by adding in a foot mount. To operate this bow, a user will secure their foot inside the toe clips attached to the foot stabilizer. This stabilizer is mounted to the bow by way of adjustable bolts. Once their foot is mounted, the user will then nock an arrow on the bowstring and securely hold the arrow in their operating hand. To draw the bowstring, the user then extends their leg to push the bow forwards, while holding their arm in the same spot. Release of the arrow is the same as a typical bow, with the user simply releasing their grasp on the arrow. This new design eliminates the need for the user to exert force with an outstretched arm and leads to a more inclusive product.



Overview of Modified Bow from Case 8



Modified Bow Foot Stabilizer from Case 8

<u>Questionnaire on Case 8: Bow</u>

The following questionnaire serves to gauge the tester's opinions on the inclusivity of the newly ladder. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how this product functions	○	○	○	○	○
2. Overall I think this product would be easy to use.	○	○	○	○	○
3. I can understand how this product addresses users with disabilities	○	○	○	○	○
4. I think this product will increase disabled users' productivity.	○	○	○	○	○
5. I think this product would make disabled users' jobs easier.	○	○	○	○	○
6. Overall, I think this product would be useful for users with disabilities	○	○	○	○	○
7. Overall, I think this product would be useful for users without disabilities	○	○	○	○	○
Additional Comments/Feedback:					

Case 15: Product Feedback

Designers should include functions in their products that allow users to perceive the current state of the product and whether or not their actions have been successful. Adding in feedback functions allows a user to know the status of their interactions with the product, and would lead to more efficient user-product interactions. Control panels are typical products that would be made more inclusive by adding in feedback functions. This functional addition would allow users to understand the effect of their actions on the product, which would make for a more effective user-product interaction.

<u>Questionnaire on Case 15: Product Feedback</u>

The following questionnaire serves to gauge the tester's opinions on the inclusivity of feedback functions. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how these changes would be implemented	◯	◯	◯	◯	◯
2. I can understand how these changes address users with disabilities.	◯	◯	◯	◯	◯
3. Overall, I think these changes would be useful for users with disabilities.	◯	◯	◯	◯	◯
4. Overall, I think these changes would be useful for users without disabilities.	◯	◯	◯	◯	◯
Additional comments/feedback					

Case 16: Alternatives to Writing

In order to develop more inclusive products, designers should provide the potential for feedback to be transmitted by alternate modes (textual, verbal, pictorial, tactile, lights, sounds). The typical written sign can exclude users who do not have good enough eyesight to read it, or who do not speak the language presented on the sign.

Applying the relevant design rules suggest that physical changes in how the sign conveys its message would make for a more inclusive sign. These physical changes include the addition of braille or other alternate forms of communication.

Questionnaire on Case 16: Alternatives to Writing

The following questionnaire serves to gauge opinions on the inclusivity of physical changes to a text sign. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how these changes would be implemented	◯	◯	◯	◯	◯
2. I can understand how these changes address users with disabilities.	◯	◯	◯	◯	◯
3. Overall, I think these changes would be useful for users with disabilities.	◯	◯	◯	◯	◯
4. Overall, I think these changes would be useful for users without disabilities.	◯	◯	◯	◯	◯
Additional comments/feedback					

Case 17: Hearing Parameters

In order to develop more inclusive products, designers should allow users to modify the parameters of audio devices (adjustable volume, pitch, tone duration) to maximize detection. Two relevant design rules suggest parametric changes to audio products, indicating that adjustments to audio devices' volume, pitch, and duration would lead to a more inclusive product. Electronic speakers, as found in many products, involve the generation of noises, and can be made more inclusive through the application of the relevant design rules.

Applying the each of the relevant design rules leads to the same result of a parametric change, suggesting to designers that changes to the parameters of the speaker, i.e changes to the pitch, volume, or duration, would lead to a more inclusive product.

<u>Questionnaire on Case 17: Hearing Parameters</u>

The following questionnaire serves to gauge opinions on the inclusivity of physical changes to a text sign. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

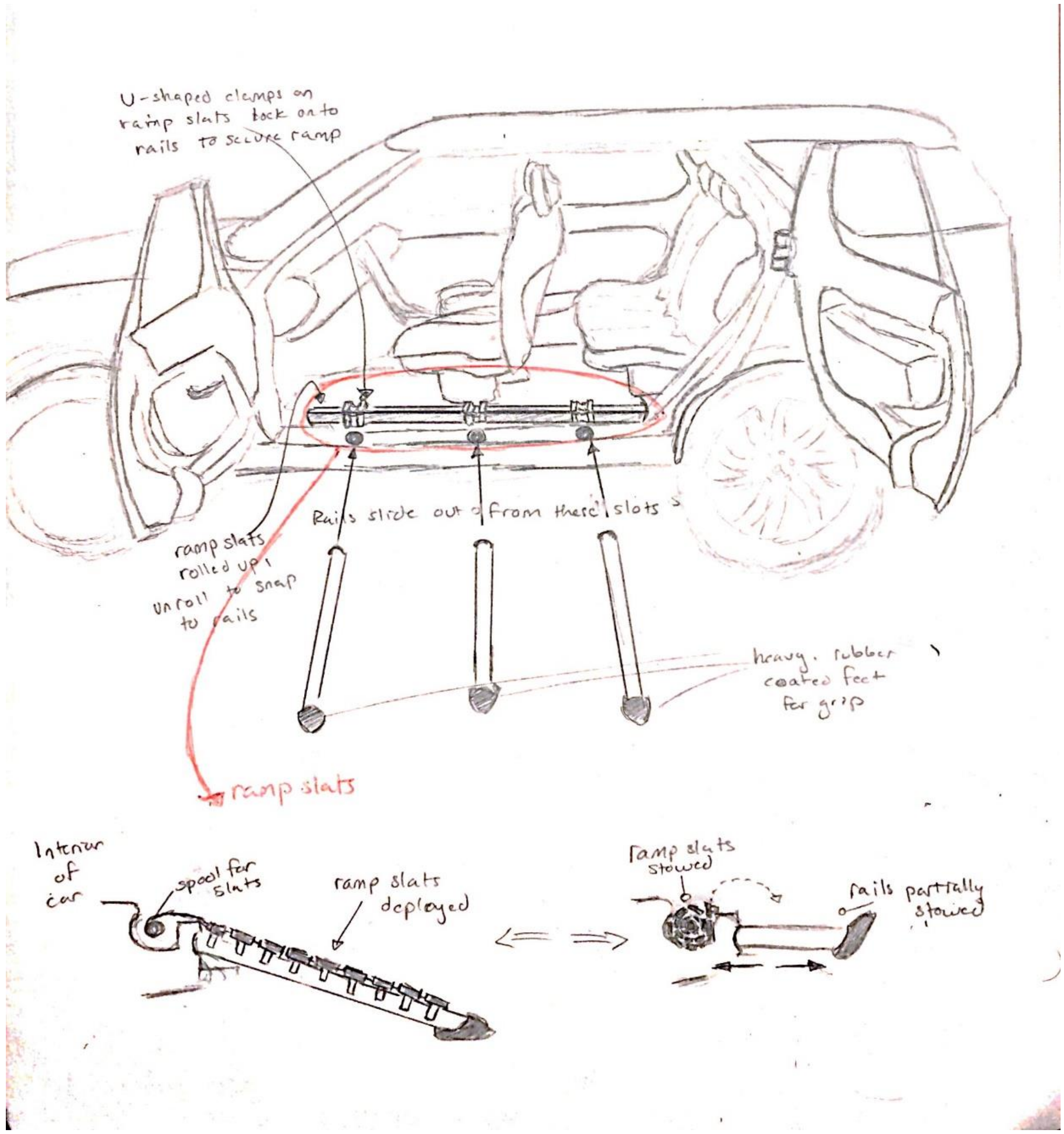
Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how these changes would be implemented	○	○	○	○	○
2. I can understand how these changes address users with disabilities.	○	○	○	○	○
3. Overall, I think these changes would be useful for users with disabilities.	○	○	○	○	○
4. Overall, I think these changes would be useful for users without disabilities.	○	○	○	○	○
Additional comments/feedback					

Case 32: Car Door, Ramp-Rail System

Designers should consider users with diminished mobility when designing the access points for products and environments. Users with mobility impairments will have trouble transferring themselves into the car through the car door unassisted, as they may lack the coordination or strength necessary to pull themselves into the car. In this case, the relevant design rule suggests by changing the physical solution to how a user enters the car in order to make the process of getting into the car easier. There are many preexisting solutions to transferring disabled users into a car, such as hydraulic lifts or personal assistance; however, these systems generally require extensive modification to the car frame or physical exertion.

A more universal solution would incorporate an inclusive method of transferring a mobility-impaired user into a car, while still being useful for typical, non-impaired users. Such a solution could include a sliding ramp on a mobile rail system that is incorporated into the car's frame. This sliding ramp solution is pictured in in the next figure.

In the sliding ramp system, there are three rails that are housed in corresponding slots under the floorboards of the car. Likewise, there is a spring loaded spool that houses metal slats that make up the ramp floor. These slats have u-shaped clamps that lock onto the rails to secure the ramp. In order to deploy the ramp, the user first slides out the rails from their housing slots. These rails have heavy, rubber coated feet that secure the rails against the ground. The user then deploys the ramp by pulling the ramp slats from their spool and locking them into position. This system creates a ramp that allows users to walk up a gradual slop in order to seat themselves in the car. Users with mobility impairments will have a much easier time slowly walking up a ramp than they have stepping up into the car from the ground.



Modified Car Door, Ramp-Rail System

Questionnaire on Case 32: Car Door, Ramp-Rail System

The following questionnaire serves to gauge the tester's opinions on the inclusivity of the newly designed car door's entry system. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how this product functions	○	○	○	○	○
2. Overall I think this product would be easy to use.	○	○	○	○	○
3. I can understand how this product addresses users with disabilities	○	○	○	○	○
4. I think this product will increase disabled users' productivity.	○	○	○	○	○
5. I think this product would make disabled users' jobs easier.	○	○	○	○	○
6. Overall, I think this product would be useful for users with disabilities	○	○	○	○	○
7. Overall, I think this product would be useful for users without disabilities	○	○	○	○	○
Additional Comments/Feedback:					

Case 34: Gas Pedal

Designers should consider users with diminished lower body strength when designing products that need to be pushed with the lower extremities. Less abled users may not have the strength or lower body dexterity to push a product with their feet or legs. In this case we consider the typical car's gas pedal. The relevant design rule in this case suggests implementing a physical change to how the user pushes the gas pedal in order to make the pedal useable by users that have little to no mobility in their legs.

This change signifies to the designer that, in order to account for lower body disabilities, the designer needs to modify the gas pedal in such a way that all functions can be accomplished by the user's body rather than their lower body. The modified product can be represented by a joystick system for accelerating and decelerating a car. Instead of using their feet to push a pedal, users can instead position a joystick, or pull a specific trigger on said joystick to trigger the accelerator and brake systems of the car. These modifications, suggested by the relevant design rule, would allow users, who would previously be unable to drive due to lower body disabilities, to operate a car's accelerator and brake systems.

<u>Questionnaire on Case 34: Gas Pedal</u>

The following questionnaire serves to gauge the tester's opinions on the inclusivity of the modified car gas pedal. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
5. I can easily understand how these changes would be implemented	○	○	○	○	○
6. I can understand how these changes address users with disabilities.	○	○	○	○	○
7. Overall, I think these changes would be useful for users with disabilities.	○	○	○	○	○
8. Overall, I think these changes would be useful for users without disabilities.	○	○	○	○	○
Additional comments/feedback					

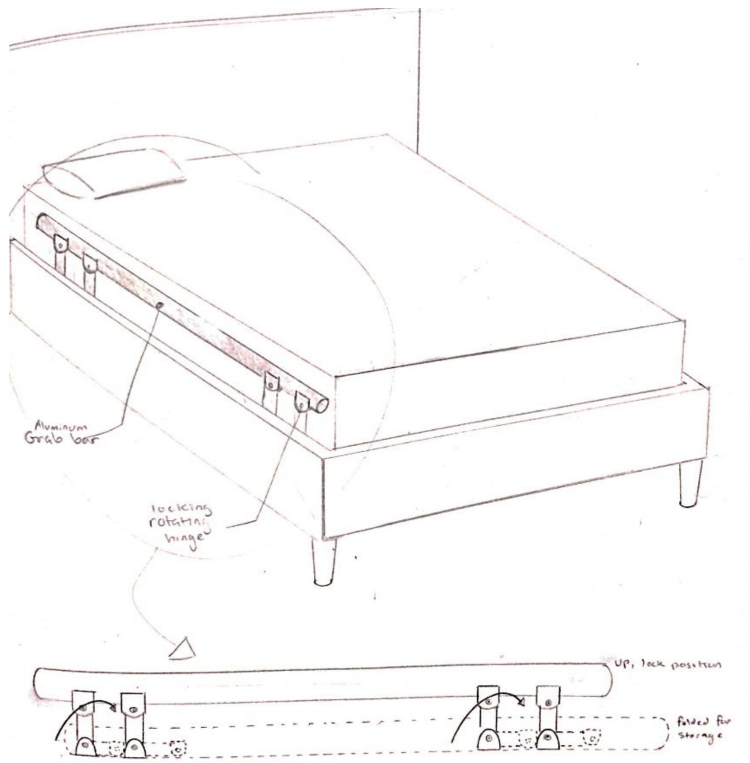
GROUP THREE

Case 11: Bed

Users with lower body disabilities have difficulty standing and sitting unsupported. Designers should take this into consideration when designing products that requires users to sit on or stand up from. In this case, the relevant design rule suggests to designers that, in order to develop a more inclusive product, components must be added that support users while they are sitting and standing using the bed. These functional additions can be accomplished by adding in a rotating grab bar that locks into position and provides users support as they change body positions.

Part 1 – Rotating Rails

The functional additions suggested by the relevant design rule in this case can be accomplished by adding in rotating grab bars. These bars will be stored in the bed frame and will remain out of sight when not in use. When the user requires support, they can pull the grab bar up into the locked position and then utilize the grab bar as support. This grab bar also serves an added function by providing a pseudo-wall that can ensure the user does not roll out of bed when sleeping.



Representation of Bed Modified with Rotating Grab Bars

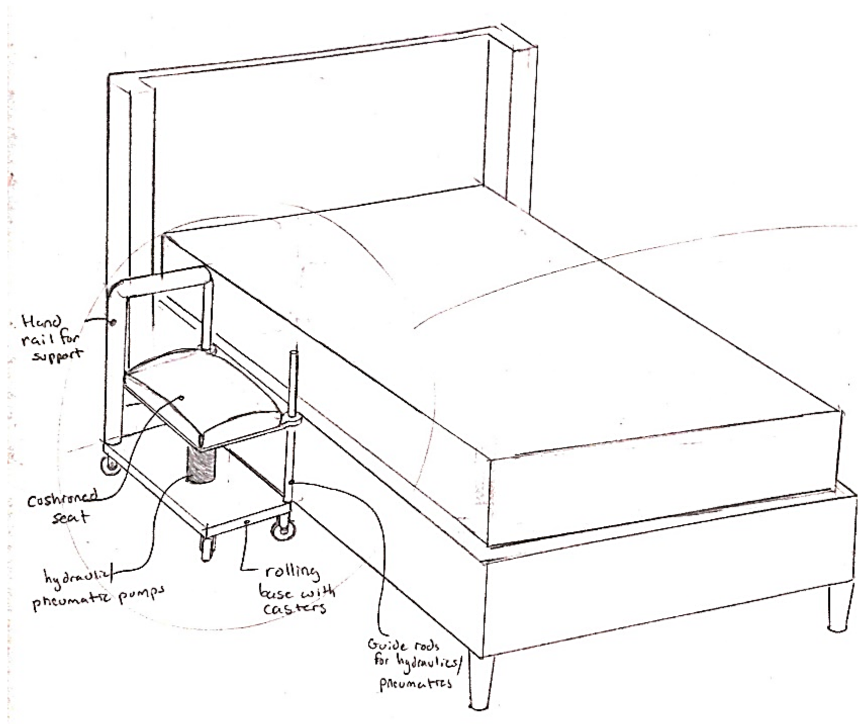
<u>Questionnaire on Case 11: Bed – Part 1: Rotating Rails</u>

The following questionnaire serves to gauge the tester's opinions on the inclusivity of the newly modified bed grab rails. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

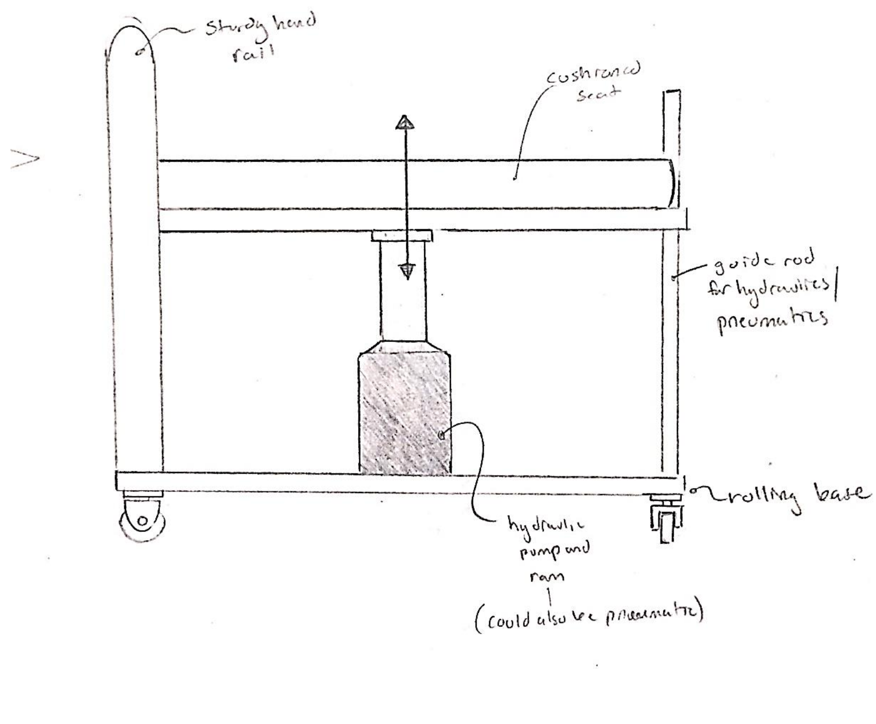
Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how this product functions	○	○	○	○	○
2. Overall I think this product would be easy to use.	○	○	○	○	○
3. I can understand how this product addresses users with disabilities	○	○	○	○	○
4. I think this product will increase disabled users' productivity.	○	○	○	○	○
5. I think this product would make disabled users' jobs easier.	○	○	○	○	○
6. Overall, I think this product would be useful for users with disabilities	○	○	○	○	○
7. Overall, I think this product would be useful for users without disabilities	○	○	○	○	○
Additional Comments/Feedback:					

Part 2 – Hydraulic Lift

A similar design rule suggests functional additions leading to a hydraulic lifting system. This lifting system is comprised of a rolling base with a large hand rail for support. The hydraulics are mounted to this rolling base, and are attached to a cushioned seat. The hydraulics and seat are guided by guide rods, and are actuated by a user-controlled panel. To sit on the bed, a user first approaches the hydraulic seat and sits on the seat at the highest position. By actuating the seat down, the user receives aid in sitting on the bed. Conversely, when wishing to stand up from the bed, a user would position themselves on the lifting seat and use the hydraulics to aid themselves in standing. The modified hydraulic lifting seat is pictured in the next figures.



Overview of Bed with Hydraulic Lift



Hydraulic Lift for Inclusive Bed

Questionnaire on Case 11: Bed – Part 2: Hydraulic Lift

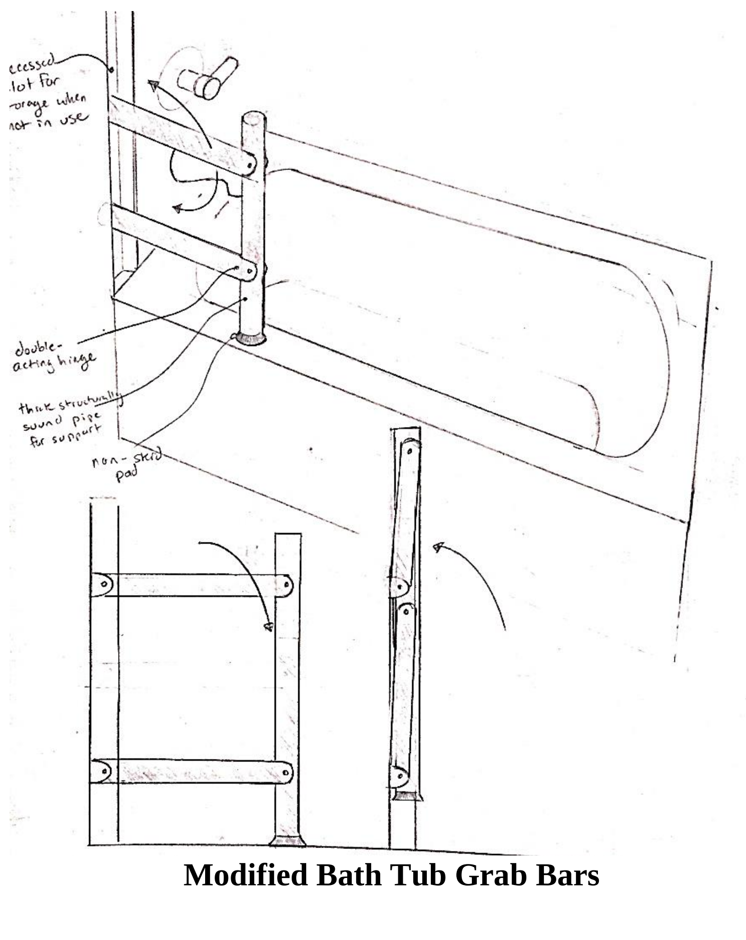
The following questionnaire serves to gauge the tester's opinions on the inclusivity of the newly modified bed with hydraulic lift. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how this product functions	○	○	○	○	○
2. Overall I think this product would be easy to use.	○	○	○	○	○
3. I can understand how this product addresses users with disabilities	○	○	○	○	○
4. I think this product will increase disabled users' productivity.	○	○	○	○	○
5. I think this product would make disabled users' jobs easier.	○	○	○	○	○
6. Overall, I think this product would be useful for users with disabilities	○	○	○	○	○
7. Overall, I think this product would be useful for users without disabilities	○	○	○	○	○
Additional Comments/Feedback:					

Case 12: Grab Bars

Grab bars and rails have the potential to be very obstructive and aesthetically displeasing. In order to avoid making products and environments look too ‘assistive’ or ‘medical’, designers should incorporate supports into the overall aesthetic of the design. By making products more aesthetically pleasing, designers can help remove some of the stigma of owning more accessible devices. By physically altering how the grab bar functions, designers can modify the product so that the rails no longer stick out as obstructive. By developing a more aesthetically pleasing product, designers can remove the stigma of owning ‘assistive’ products, which could lead to more widespread use of the inclusive products.

Consider the typical grab bars on a bath tub. Typically grab bars on bath tubs are seen as ‘assistive’ products, and could turn away some users. By instead utilizing a set of rotating grab bars, designers can ensure that the grab bars do not get in the way of normal operation of the bath tub. A representation of the modified bath tub grab bars is shown in the next image.



Modified Bath Tub Grab Bars

Questionnaire on Case 12: Grab Bars

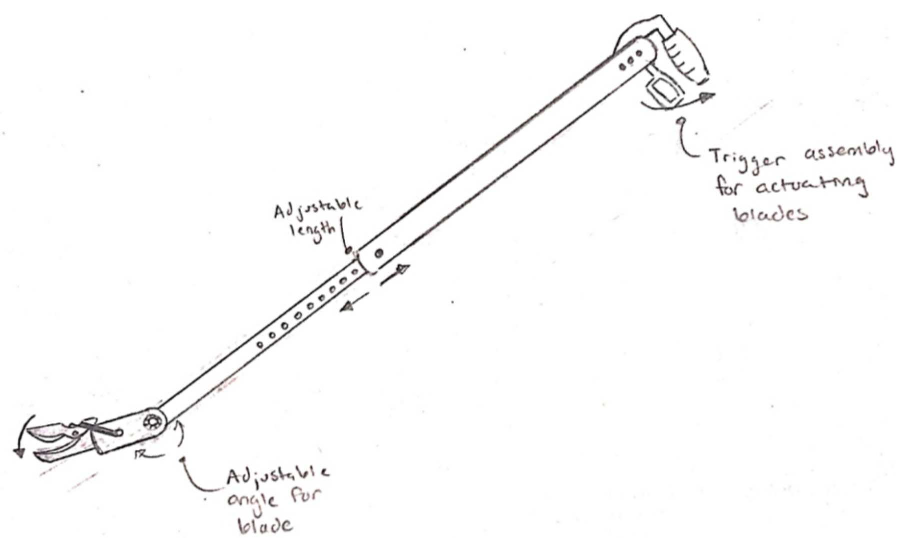
The following questionnaire serves to gauge the tester's opinions on the inclusivity of the newly modified bath tub grab bars. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
8. I can easily understand how this product functions	○	○	○	○	○
9. Overall I think this product would be easy to use.	○	○	○	○	○
10. I can understand how this product addresses users with disabilities	○	○	○	○	○
11. I think this product will increase disabled users' productivity.	○	○	○	○	○
12. I think this product would make disabled users' jobs easier.	○	○	○	○	○
13. Overall, I think this product would be useful for users with disabilities	○	○	○	○	○
14. Overall, I think this product would be useful for users without disabilities	○	○	○	○	○
Additional Comments/Feedback:					

Case 13: Garden Shears

Users with limited lower body ability or back trouble have trouble bending at the waist. In order to develop more inclusive designs, designers should consider removing the need to bend over to utilize the product. A typical product that requires users to bend over during is a set of garden shears, which require the user to bend over to couple the shears with low-lying vegetation.

The relevant design rule suggests a change to the physical method that a user brings the garden shears in contact with a plant or other object so that a user does not have to bend over in order to use the product. A sketch of the newly modified garden shears is shown in in the next figure. For the purpose of this case, we have modified the overall length of the garden shears by incorporating an adjustable length handle. This handle allows the user to adjust the length of the shears as desired, while a lockable rotating blade head allows the user to adjust the angle of the blades in order to account for all angles of use. The new garden shears' blades are actuated by the user pulling a trigger on the handle, which in turn pulls on a cable inside the handle that attaches to the blades. The cable that actuates the garden shear blades entails a new physical method of transferring human energy to move the blades. In order to account for the adjustable length of the garden shears, the cable is wound around a spring-loaded reel that ensures the cable length is always compatible with the handle length. This new design for garden shears, suggested by a relevant inclusive design rule, will allow users to utilize the shears on low-lying plants without having to bend over.



Modified Garden Shears

Questionnaire on Case 13: Garden Shears

The following questionnaire serves to gauge the tester's opinions on the inclusivity of the newly modified garden shears. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how this product functions	○	○	○	○	○
2. Overall I think this product would be easy to use.	○	○	○	○	○
3. I can understand how this product addresses users with disabilities	○	○	○	○	○
4. I think this product will increase disabled users' productivity.	○	○	○	○	○
5. I think this product would make disabled users' jobs easier.	○	○	○	○	○
6. Overall, I think this product would be useful for users with disabilities	○	○	○	○	○
7. Overall, I think this product would be useful for users without disabilities	○	○	○	○	○
Additional Comments/Feedback:					

Case 18: Alternatives to Sound Signals

In order to develop more inclusive audio products, designers should strive to utilize lower pitched, natural tones in comparison to higher pitched, synthesized tones. Additionally, designers should allow for secondary forms of communication alongside auditory messages. The typical public address system can exclude users with impaired hearing, or those who do not speak the language of the speaker's message.

The relevant design rules suggest to designers that changes to how the public address system conveys its message would lead to a more inclusive product. These rules suggest a physical change in how the system conveys its message, and suggests to designers that allowing alternative forms of communication would make the public address system more inclusive. A designer could add in a speech to text display to provide a visual readout of the speaker's message for the hearing impaired, or modify the system to utilize a more natural tone of voice for more clarity.

Questionnaire on Case 18: Alternatives to Sound Signals

The following questionnaire serves to gauge opinions on the inclusivity of physical changes to a text sign. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how these changes would be implemented	◯	◯	◯	◯	◯
2. I can understand how these changes address users with disabilities.	◯	◯	◯	◯	◯
3. Overall, I think these changes would be useful for users with disabilities.	◯	◯	◯	◯	◯
4. Overall, I think these changes would be useful for users without disabilities.	◯	◯	◯	◯	◯
Additional comments/feedback					

Case 19: Alterations to Text

Users with poor eyesight have difficulties reading small or decorative text. In order to develop more accessible products utilizing texts, designers should strive to employ larger and more legible fonts. Larger, sans-serif fonts are more easily distinguished by users with impaired eyesight than decorative or cursive font styles. Additionally, designers should use plain, instead of patterned, backgrounds whenever possible to aid users in distinguishing text from the background.

The relevant design rules in this case suggest modifications to the text size, font type, and background style. Modifying these parameters would help to make text more legible and accessible to sight-impaired users. Below are examples of changes in text parameters.

Less Inclusive (hard to read)		**More Inclusive (easier to read)**
Smaller text	→	Larger Text
Serif fonts	→	Sans-Serif fonts
Decorative Fonts	→	Normal style fonts
Narrow fonts	→	Normal width
Patterned Background	→	Plain Background

Questionnaire on Case 19: Alterations to Text

Please consult the above table of text and answer the following questions to the best of your abilities.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how these changes would be implemented	○	○	○	○	○
2. I can understand how these changes address users with disabilities.	○	○	○	○	○
3. Overall, I think these changes would be useful for users with disabilities.	○	○	○	○	○
4. Overall, I think these changes would be useful for users without disabilities.	○	○	○	○	○
Additional comments/feedback					

Case 20: Alterations to Charts and Images

Users with poor eyesight have difficulties reading and differentiating low contrast or small graphical symbols. Additionally, designers should keep all the forms of color blindness when setting the color palette of a product. In this case, relevant design rules suggest modifying the parameters of charts and images so that they will be more inclusive to more users.

The parametric changes suggested by the application of these rules could include modifications to the color scheme, image sizes, or contrast levels. Modifications to the chart parameters would lead to a more legible and accessible chart or image. These design rules can be utilized by designers on any product involving informative graphics or charts in order to help users understand their meaning.

<u>Questionnaire on Case 20: Alterations to Charts and Images</u>

The following questions serve to gauge the tester's views on the inclusivity of modified charts and images. Please answer to the best of your abilities.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how these changes would be implemented	◯	◯	◯	◯	◯
2. I can understand how these changes address users with disabilities.	◯	◯	◯	◯	◯
3. Overall, I think these changes would be useful for users with disabilities.	◯	◯	◯	◯	◯
4. Overall, I think these changes would be useful for users without disabilities.	◯	◯	◯	◯	◯
Additional comments/feedback					

Case 30: Securing Users

Designers should consider users with diminished mobility when designing products and environments. In order to develop more inclusive products and environments, designers should consider adding in functions pertaining to securing the user as the user moves around. In this case, the relevant design rule suggests adding in the means to secure users when they are moving around in an environment.

Designers could make the environment more inclusive by incorporating hand rails or walls for users to brace themselves on. Designers could also satisfy this functional addition by adding in seating areas or benches to allow uses to support themselves as they move through the environment. Components such as benches and hand rails would allow users to secure and steady themselves as they move through the environment, therefore making that environment more accessible.

Questionnaire on Case 30: Securing Users

The following questionnaire serves to gauge the tester's opinions on the inclusivity of adding in certain products to environments that users walk through. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how these changes would be implemented	○	○	○	○	○
2. I can understand how these changes address users with disabilities.	○	○	○	○	○
3. Overall, I think these changes would be useful for users with disabilities.	○	○	○	○	○
4. Overall, I think these changes would be useful for users without disabilities.	○	○	○	○	○
Additional comments/feedback					

Case 34: Gas Pedal

Designers should consider users with diminished lower body strength when designing products that need to be pushed with the lower extremities. Less abled users may not have the strength or lower body dexterity to push a product with their feet or legs. In this case we consider the typical car's gas pedal. The relevant design rule in this case suggests implementing a physical change to how the user pushes the gas pedal in order to make the pedal useable by users that have little to no mobility in their legs.

This change signifies to the designer that, in order to account for lower body disabilities, the designer needs to modify the gas pedal in such a way that all functions can be accomplished by the user's body rather than their lower body. The modified product can be represented by a joystick system for accelerating and decelerating a car. Instead of using their feet to push a pedal, users can instead position a joystick, or pull a specific trigger on said joystick to trigger the accelerator and brake systems of the car. These modifications, suggested by the relevant design rule, would allow users, who would previously be unable to drive due to lower body disabilities, to operate a car's accelerator and brake systems.

<u>Questionnaire on Case 34: Gas Pedal</u>

The following questionnaire serves to gauge the tester's opinions on the inclusivity of the modified car gas pedal. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how these changes would be implemented	○	○	○	○	○
2. I can understand how these changes address users with disabilities.	○	○	○	○	○
3. Overall, I think these changes would be useful for users with disabilities.	○	○	○	○	○
4. Overall, I think these changes would be useful for users without disabilities.	○	○	○	○	○
Additional comments/feedback					

GROUP FOUR

Case 21: Anti-Glare Screen

In order to make environments and products more accessible to all users, designers should consider reducing glare by avoiding highly reflective surfaces and allowing for light sources and screens to be easily repositioned. In this case, we consider the typical computer or television screen. In this case, the relevant design rule suggests physical changes to products and/or environments to modify how products' screens indicate information to the user. In order to create a more accessible scree, designers should incorporate solutions to the issues of glare and repositionability.

Questionnaire on Case 21: Anti-Glare Screen

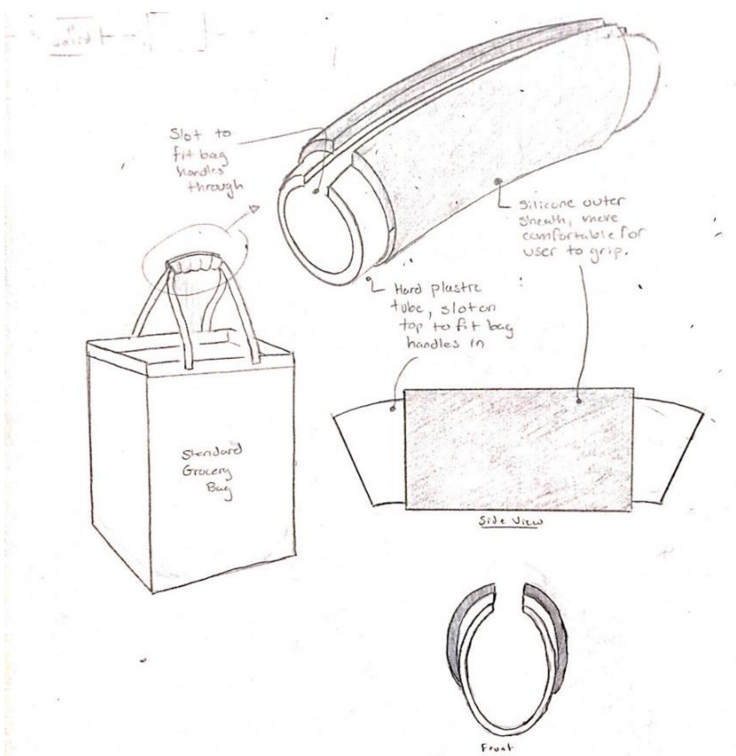
The following questions serve to gauge the tester's views on the inclusivity of modified product screens and environments.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how these changes would be implemented	◯	◯	◯	◯	◯
2. I can understand how these changes address users with disabilities.	◯	◯	◯	◯	◯
3. Overall, I think these changes would be useful for users with disabilities.	◯	◯	◯	◯	◯
4. Overall, I think these changes would be useful for users without disabilities.	◯	◯	◯	◯	◯
Additional comments/feedback					

Case 22: Grocery Bags

In order to make environments and products more accessible to all users, designers should consider changes to how a user positions their hands on the product to move or otherwise handle the object. Users with upper body disabilities will have difficulty grasping or carrying certain shapes of objects, so designers should consider parametric changes in order to develop more inclusive products. . Changing the parameters of how the user grips and carries the bag would help to make a more accessible product.

Holding and carrying a grocery bag can be difficult for several reasons. The handles are narrow and do not provide much room for gripping, and the handle can cut into the users hand. A possible solution designers could implement is a hard carrying handle that can attach to grocery bags. This proposed solution, pictured in the next figure, utilizes a U-shaped hard plastic tube with a slot to fit bag handles into. This tube also has a silicone outer sheath, for a more comfortable grip while the user carries the bag. This design, suggested by the relevant design rule, would allow users with hand impairments or other disabilities to grip multiple grocery bags comfortably in one hand.



Modified Grocery Bag Holder

<u>Questionnaire on Case 22: Grocery Bags</u>

The following questionnaire serves to gauge the tester's opinions on the inclusivity of the newly modified grocery bag holder. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how this product functions	◯	◯	◯	◯	◯
2. Overall I think this product would be easy to use.	◯	◯	◯	◯	◯
3. I can understand how this product addresses users with disabilities	◯	◯	◯	◯	◯
4. I think this product will increase disabled users' productivity.	◯	◯	◯	◯	◯
5. I think this product would make disabled users' jobs easier.	◯	◯	◯	◯	◯
6. Overall, I think this product would be useful for users with disabilities	◯	◯	◯	◯	◯
7. Overall, I think this product would be useful for users without disabilities	◯	◯	◯	◯	◯
Additional Comments/Feedback:					

Case 23: Microwave

In order to make environments and products more accessible to all users, designers should consider how users move and position objects in a system. Users with upper body disabilities will have difficulty grasping or carrying certain shapes of objects, or handling objects inside areas that are too small, so designers should consider changing certain product dimensions in order to develop more inclusive products. It may be difficult for impaired users to manipulate their hands and arms in the tight confines of typical microwaves. In this case, the relevant design rule suggests modifying the microwaves dimensions and parameters in order to make the microwave easier to use for mobility impaired users. These modifications could include adjustments to the size of the microwave chamber, or modifications to parameters in the door to allow the chamber to open wider.

<u>Questionnaire on Case 23: Microwaves</u>

The following questions serve to gauge the tester's views on the inclusivity of the modified microwave. Please provide comments and feedback as you see fit, and answer the questions to the best of your ability.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how these changes would be implemented	◯	◯	◯	◯	◯
2. I can understand how these changes address users with disabilities.	◯	◯	◯	◯	◯
3. Overall, I think these changes would be useful for users with disabilities.	◯	◯	◯	◯	◯
Additional Feedback/ comments					

Case 24: Push Button

In order to make products with controls more accessible to all users, designers should consider utilizing push buttons rather than other forms of control switches such as toggles and dials. Push buttons are far easier for users with impaired hands to actuate than rotating dials or flipping toggle switches, as the motion of pushing is far simpler and more easily accomplished than gripping and twisting. The relevant design suggests that, in the case of a general switch, designers should strive to utilize push buttons instead of other types of switches, in order to develop a more inclusive product. Push buttons can be actuated by any appendage, and require no grip strength or fine motor skills to operate, and thus are more inclusive than other types of switches.

Questionnaire on Case 24 Push Button

The following questions serve to gauge the tester's views on the inclusivity of the modified push buttons with respect to general turn and toggle switches. Please provide comments and feedback as you see fit, and answer the questions to the best of your ability.

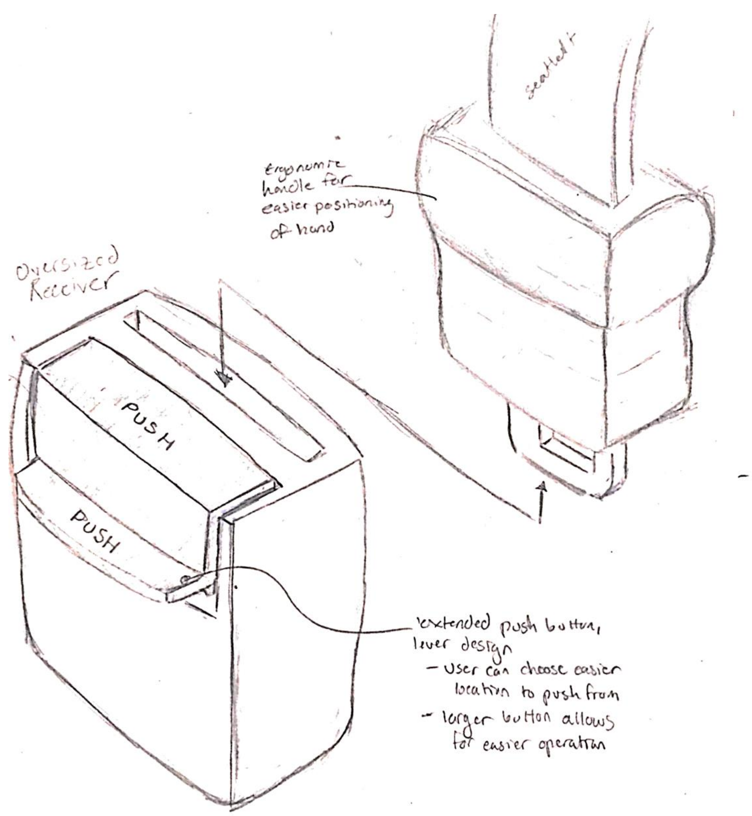
Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how these changes would be implemented	○	○	○	○	○
2. I can understand how these changes address users with disabilities.	○	○	○	○	○
3. Overall, I think these changes would be useful for users with disabilities.	○	○	○	○	○
4. Overall, I think these changes would be useful for users without disabilities.	○	○	○	○	○
Additional comments/feedback					

Case 25: Seat Belt

In order to make products more accessible to all users, designers should consider changing certain parameters of the product relating to how a user would grip and guide parts of the product. Individuals with reduced grip strength may have difficulties manipulating small or unfamiliarly shaped objects. In this case, given design rules to a typical seat belt.

The relevant design rule in this case suggests changes that are all aimed at making the actions of gripping, latching, and unlatching the seat belt more inclusive. These modified functions can be physically represented by the sketched seat belt in the next figure. This modified seat belt has an oversized ergonomic handle for easier positioning of the user's hand. Additionally, the modified seat belt utilizes an extended push button with a stepped design which allows the user to more easily brace their fingers against the bottom of the seat belt latch while pushing down on the button. Additionally, the larger push button provides a larger area for the user to press on, so that they can use their hand, palm, or various other appendages to push rather than just their fingers.

<u>Questionnaire on Case 25: Seat Belt</u>



Modified Seat Belt

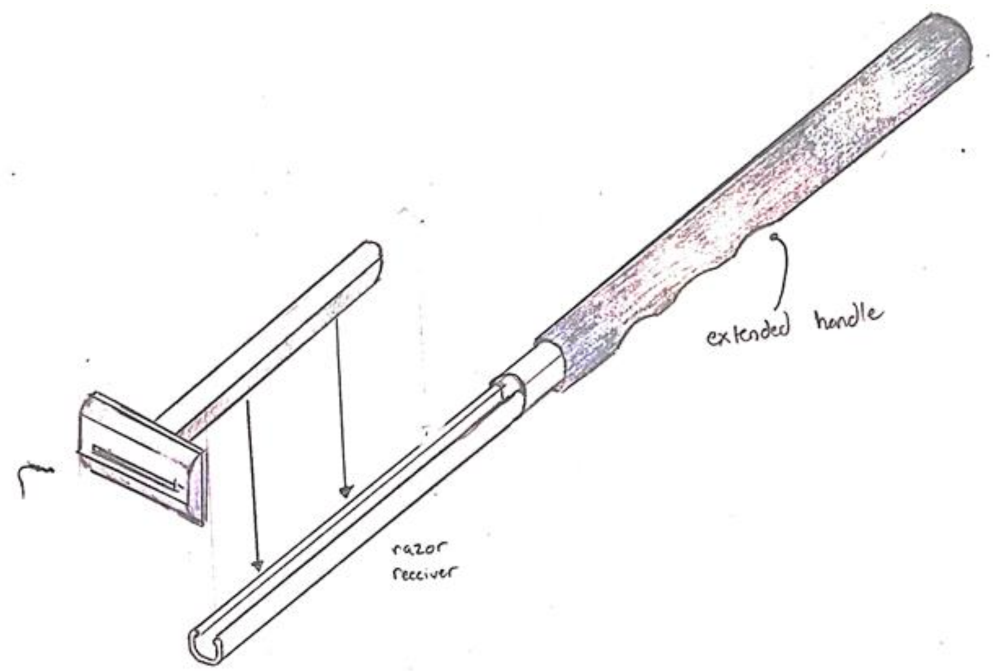
The following questionnaire serves to gauge the tester's opinions on the inclusivity of the newly modified seat belt. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how this product functions	○	○	○	○	○
2. Overall I think this product would be easy to use.	○	○	○	○	○
3. I can understand how this product addresses users with disabilities	○	○	○	○	○
4. I think this product will increase disabled users' productivity.	○	○	○	○	○
5. I think this product would make disabled users' jobs easier.	○	○	○	○	○
6. Overall, I think this product would be useful for users with disabilities	○	○	○	○	○
7. Overall, I think this product would be useful for users without disabilities	○	○	○	○	○
Additional Comments/Feedback:					

Case 26: Extended Razor

In order to make products more accessible to all users, designers should consider changing certain parameters of products relating to how a user brings the products in contact with other objects. In this case, we consider a typical shaving razor, which users need to couple with their leg or other body parts in order to cut hair. The relevant design rule suggests changes to the parameters of the razor that are involved in contacting the razor with the user's limbs. In this case, these modifications can be represented by the modified, extended handle razor in the next figure.

The extended handle razor allows a user to attach a standard sized razor to an ergonomic



Modified Extended Handle Razor

extended handle. The added length from the extended handle allows users to use the razor on farther to reach locations of their body without having to physically reach with their arms as much as they would with a typical razor. This modification should make coupling the razor with the user's limbs much easier, and therefore leads to a more inclusive product.

<u>Questionnaire on Case 26: Extended Razor</u>

The following questionnaire serves to gauge the tester's opinions on the inclusivity of the newly modified extended razor. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how this product functions	○	○	○	○	○
2. Overall I think this product would be easy to use.	○	○	○	○	○
3. I can understand how this product addresses users with disabilities	○	○	○	○	○
4. I think this product will increase disabled users' productivity.	○	○	○	○	○
5. I think this product would make disabled users' jobs easier.	○	○	○	○	○
6. Overall, I think this product would be useful for users with disabilities	○	○	○	○	○
7. Overall, I think this product would be useful for users without disabilities	○	○	○	○	○
Additional Comments/Feedback:					

Case 27: Clothes Iron

In order to make products more accessible to all users, designers should consider changing certain parameters of the product relating to how a user guides a part of the product by pulling. Persons with upper body disabilities may not have the proper strength required to pull part of a product, and parametric changes may lead to a better situation. In this case we apply the given design rule to a typical iron. Users with upper body impairments could have difficulty moving the iron due to its weight. The relevant design rule suggests modifying certain parameters of the clothes iron, and should lead designers to developing a more inclusive product.

The suggested changes to the clothes iron's parameters could include modifying the overall size and weight of the clothes iron. By utilizing lighter-weight materials and lowering the overall size of the product, designers can develop a clothes iron that is easier for all users, impaired or able, to use.

Questionnaire on Case 27: Clothes Iron

The following questionnaire serves to gauge the tester's opinions on the inclusivity of certain changes to a typical clothes iron. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how these changes would be implemented	○	○	○	○	○
2. I can understand how these changes address users with disabilities.	○	○	○	○	○
3. Overall, I think these changes would be useful for users with disabilities.	○	○	○	○	○
4. Overall, I think these changes would be useful for users without disabilities.	○	○	○	○	○
Additional comments/feedback					

Case 29: Turn Switches

Designers should consider users with diminished hand strength when designing turn switches on products. Users with reduced hand function have more difficulties grasping and twisting objects in comparison to pushing them. Designers can change the parameters of a product to create a mechanical advantage such that users can cause an object to turn by pushing on the end of it.

Users with hand impairments have difficulty gripping and physically turning turn switches. In this case, the relevant design rule suggests that parametric changes to the switch would lead to a more inclusive product. Parametric changes to the switch's length would give the user a mechanical advantage and allow them to turn the switch by applying force with their fingers. Redesigning the dimensions of the turn dial so users can turn the switch by pushing makes for a more inclusive method of actuating power in a product.

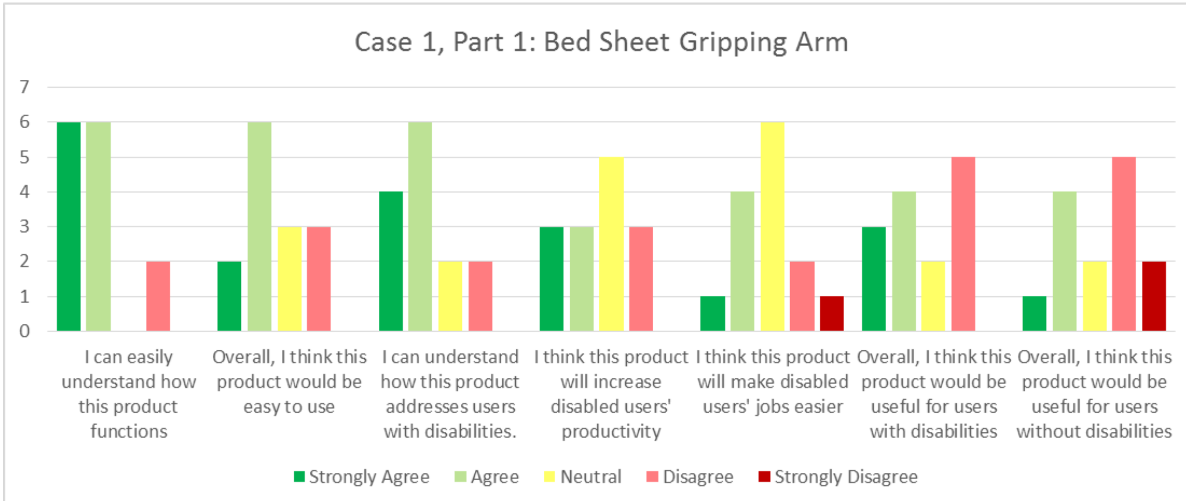
Questionnaire on Case 29: Turn Switches

The following questionnaire serves to gauge the tester's opinions on the inclusivity of push buttons. Please fill out this questionnaire to the best of your ability and provide additional comments and feedback as you see fit.

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can easily understand how these changes would be implemented	○	○	○	○	○
2. I can understand how these changes address users with disabilities.	○	○	○	○	○
3. Overall, I think these changes would be useful for users with disabilities.	○	○	○	○	○
4. Overall, I think these changes would be useful for users without disabilities.	○	○	○	○	○
Additional comments/feedback					

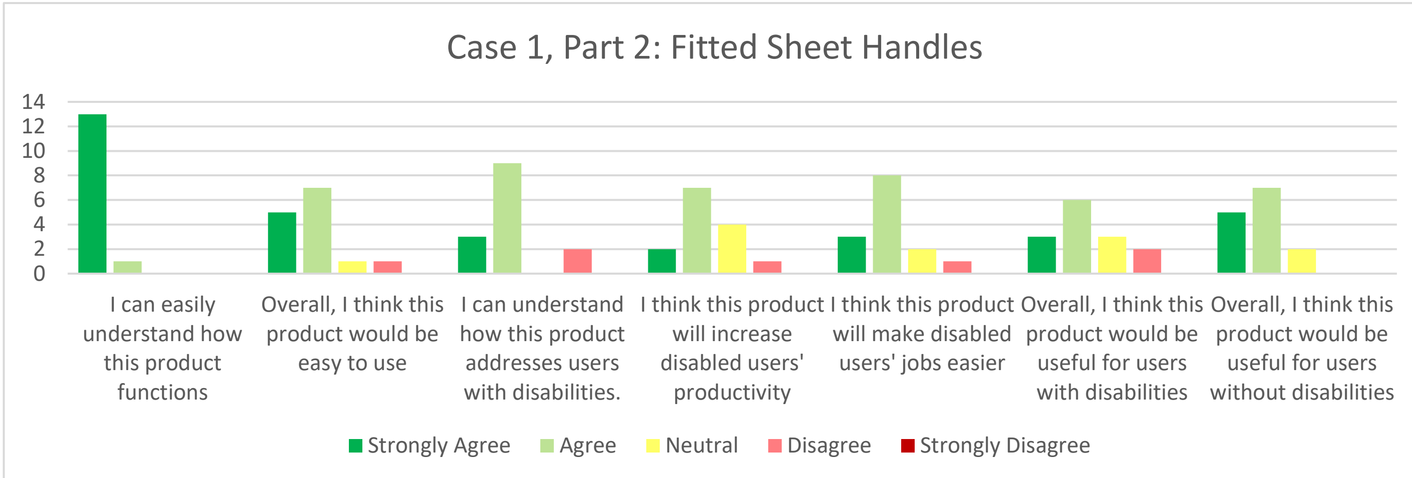
APPENDIX F: EXPERIMENTAL SURVEY RESULTS

Case 1.1: Bed Sheet Gripping Arm



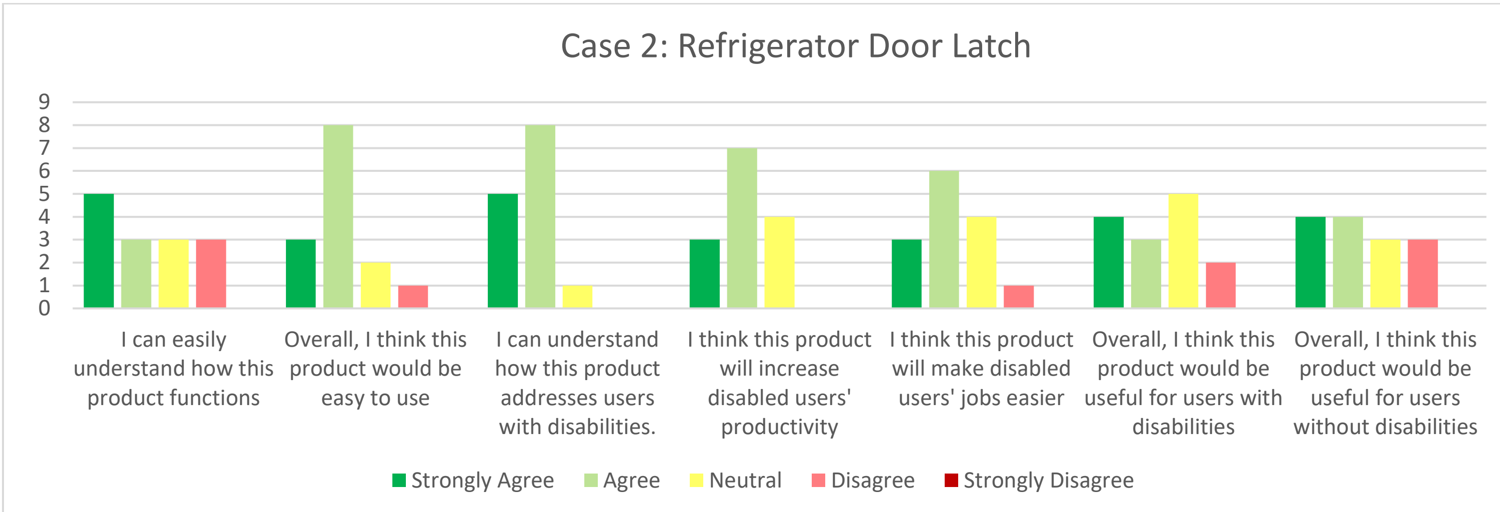
	I can easily understand how this product functions	Overall, I think this product would be easy to use	I can understand how this product addresses users with disabilities.	I think this product will increase disabled users' productivity	I think this product will make disabled users' jobs easier	Overall, I think this product would be useful for users with disabilities	Overall, I think this product would be useful for users without disabilities	**Perceived Inclusivity (median)**
Strongly Agree	6	2	4	3	1	3	1	3
Agree	6	6	6	3	4	4	4	
Neutral	0	3	2	5	6	2	2	
Disagree	2	3	2	3	2	5	5	
Strongly Disagree	0	0	0	0	1	0	2	
Median	**4**	**4**	**4**	**3**	**3**	**3.5**	**2.5**	

Case 1.2: Fitted Sheet Handles



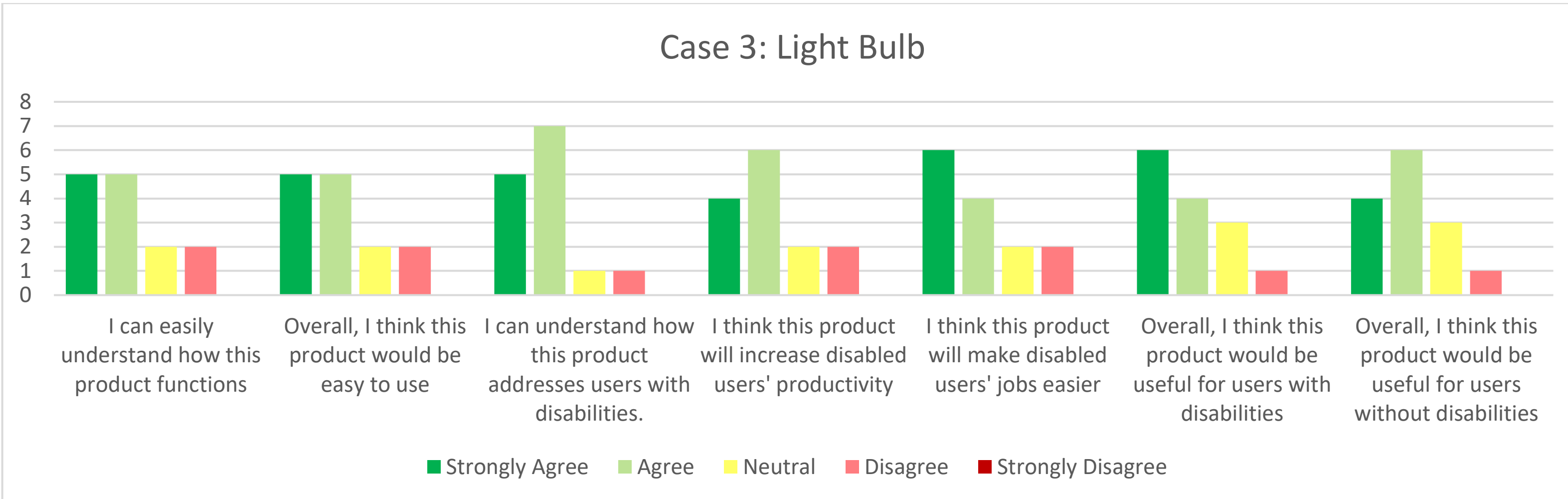
	I can easily understand how this product functions	Overall, I think this product would be easy to use	I can understand how this product addresses users with disabilities.	I think this product will increase disabled users' productivity	I think this product will make disabled users' jobs easier	Overall, I think this product would be useful for users with disabilities	Overall, I think this product would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	13	5	3	2	3	3	5	4
Agree	1	7	9	7	8	6	7	
Neutral	0	1	0	4	2	3	2	
Disagree	0	1	2	1	1	2	0	
Strongly Disagree	0	0	0	0	0	0	0	
Median	**5**	**4**	**4**	**4**	**4**	**4**	**4**	

Case 2: Refrigerator Door Latches



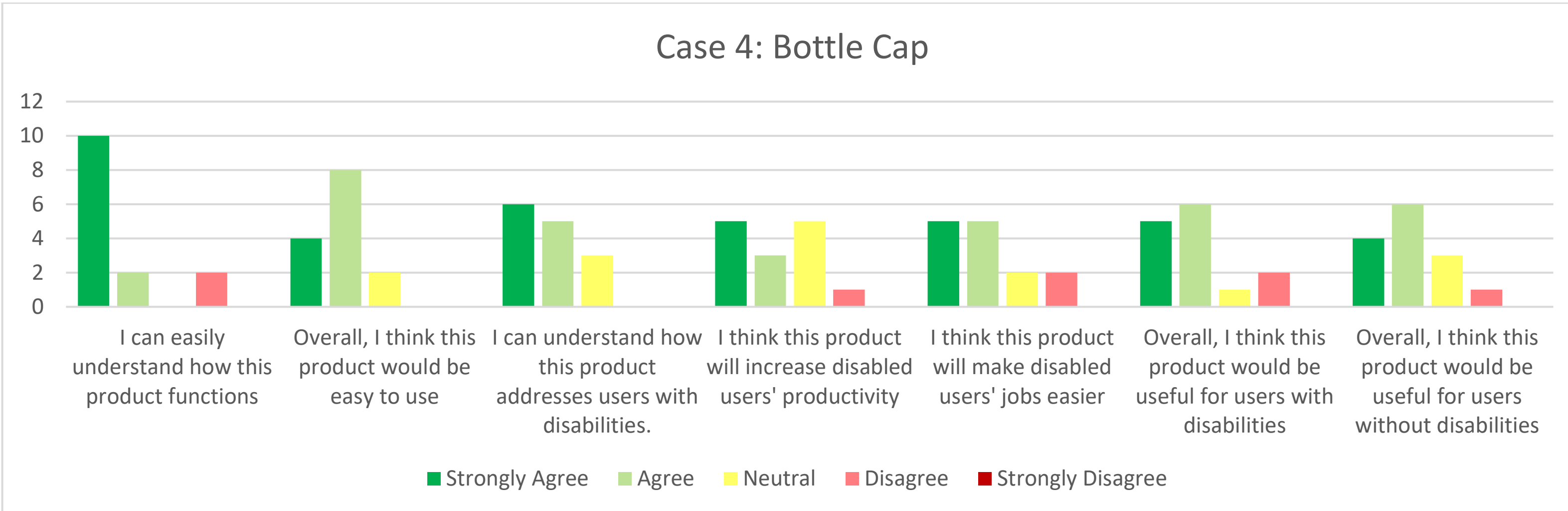
	I can easily understand how this product functions	Overall, I think this product would be easy to use	I can understand how this product addresses users with disabilities.	I think this product will increase disabled users' productivity	I think this product will make disabled users' jobs easier	Overall, I think this product would be useful for users with disabilities	Overall, I think this product would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	5	3	5	3	3	4	4	4
Agree	3	8	8	7	6	3	4	
Neutral	3	2	1	4	4	5	3	
Disagree	3	1	0	0	1	2	3	
Strongly Disagree	0	0	0	0	0	0	0	
Median	**4**	**4**	**4**	**4**	**4**	**3.5**	**4**	

Case 3: Light Bulb



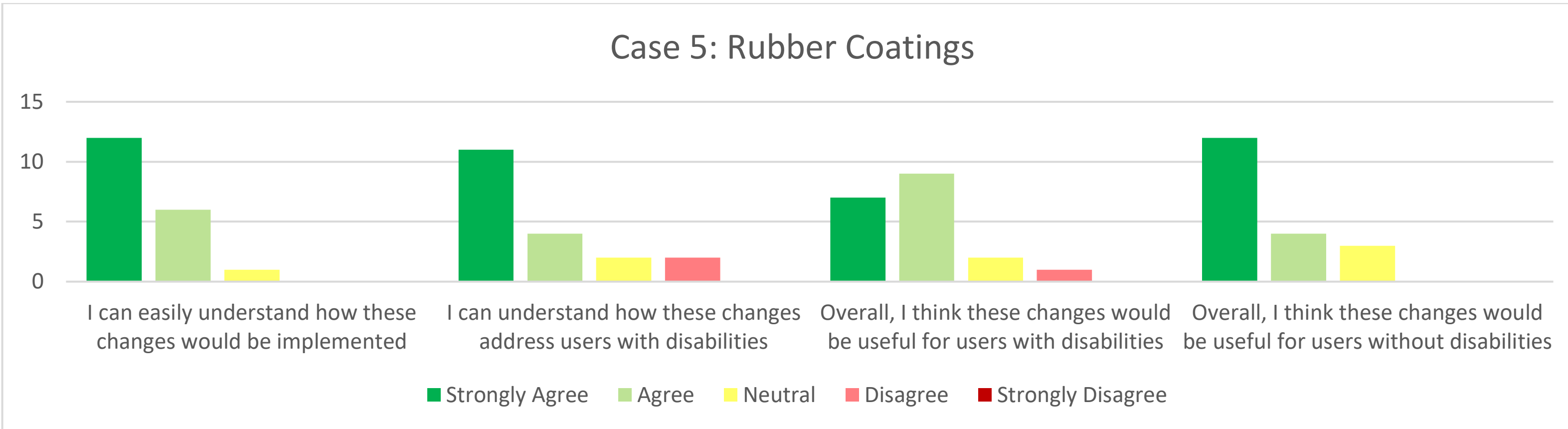
	I can easily understand how this product functions	Overall, I think this product would be easy to use	I can understand how this product addresses users with disabilities.	I think this product will increase disabled users' productivity	I think this product will make disabled users' jobs easier	Overall, I think this product would be useful for users with disabilities	Overall, I think this product would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	5	5	5	4	6	6	4	4
Agree	5	5	7	6	4	4	6	
Neutral	2	2	1	2	2	3	3	
Disagree	2	2	1	2	2	1	1	
Strongly Disagree	0	0	0	0	0	0	0	
Median	**4**	**4**	**4**	**4**	**4**	**4**	**4**	

Case 4: Bottle Cap



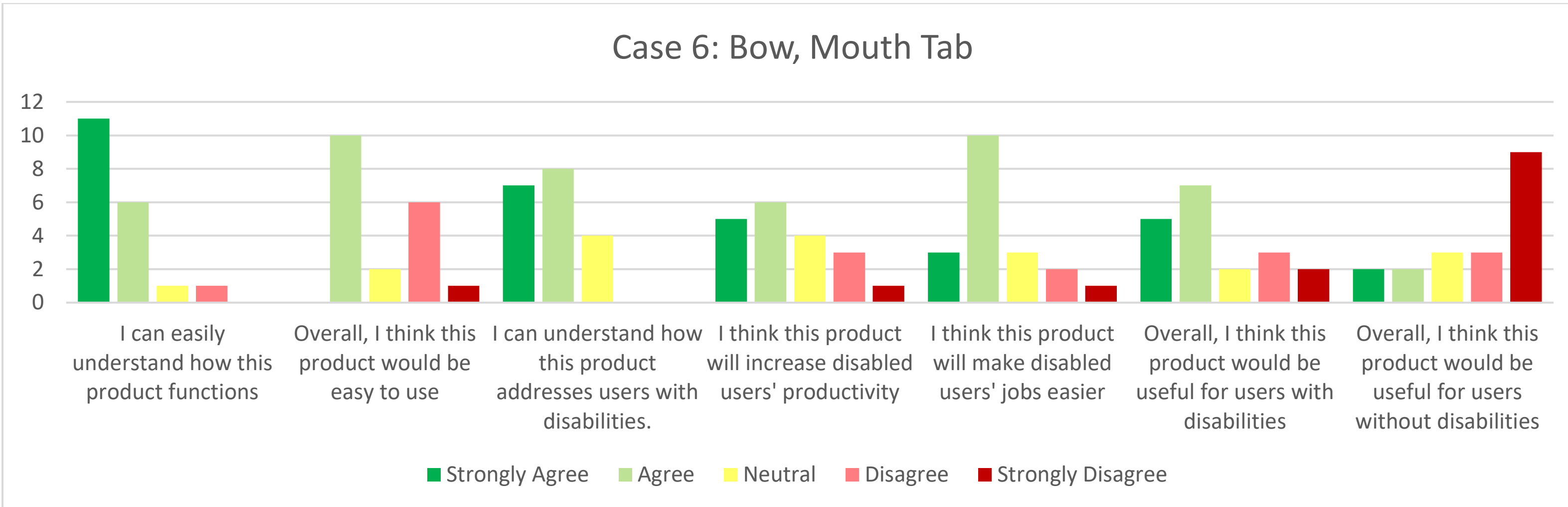
	I can easily understand how this product functions	Overall, I think this product would be easy to use	I can understand how this product addresses users with disabilities.	I think this product will increase disabled users' productivity	I think this this product will make disabled users' jobs easier	Overall, I think this product would be useful for users with disabilities	Overall, I think this product would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	10	4	6	5	5	5	4	4
Agree	2	8	5	3	5	6	6	
Neutral	0	2	3	5	2	1	3	
Disagree	2	0	0	1	2	2	1	
Strongly Disagree	0	0	0	0	0	0	0	
Question Median	**5**	**4**	**4**	**4**	**4**	**4**	**4**	

Case 5: Rubber Coatings



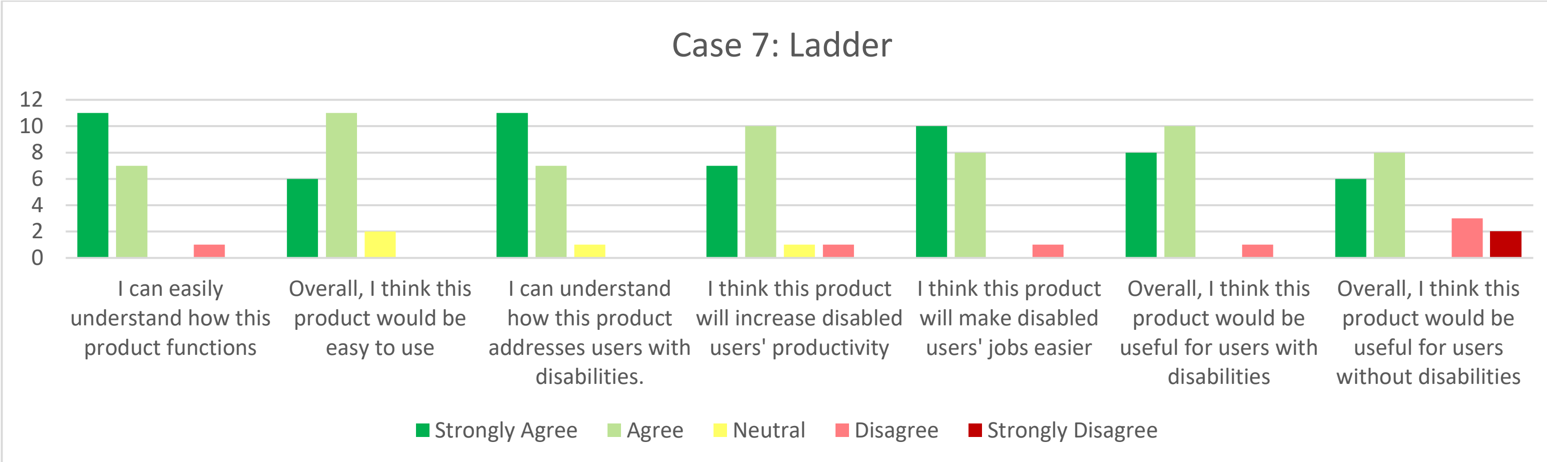
	I can easily understand how these changes would be implemented	I can understand how these changes address users with disabilities	Overall, I think these changes would be useful for users with disabilities	Overall, I think these changes would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	12	11	7	12	5
Agree	6	4	9	4	
Neutral	1	2	2	3	
Disagree	0	2	1	0	
Strongly Disagree	0	0	0	0	
Median	**5**	**5**	**4**	**5**	

Case 6: Bow, Mouth Tab



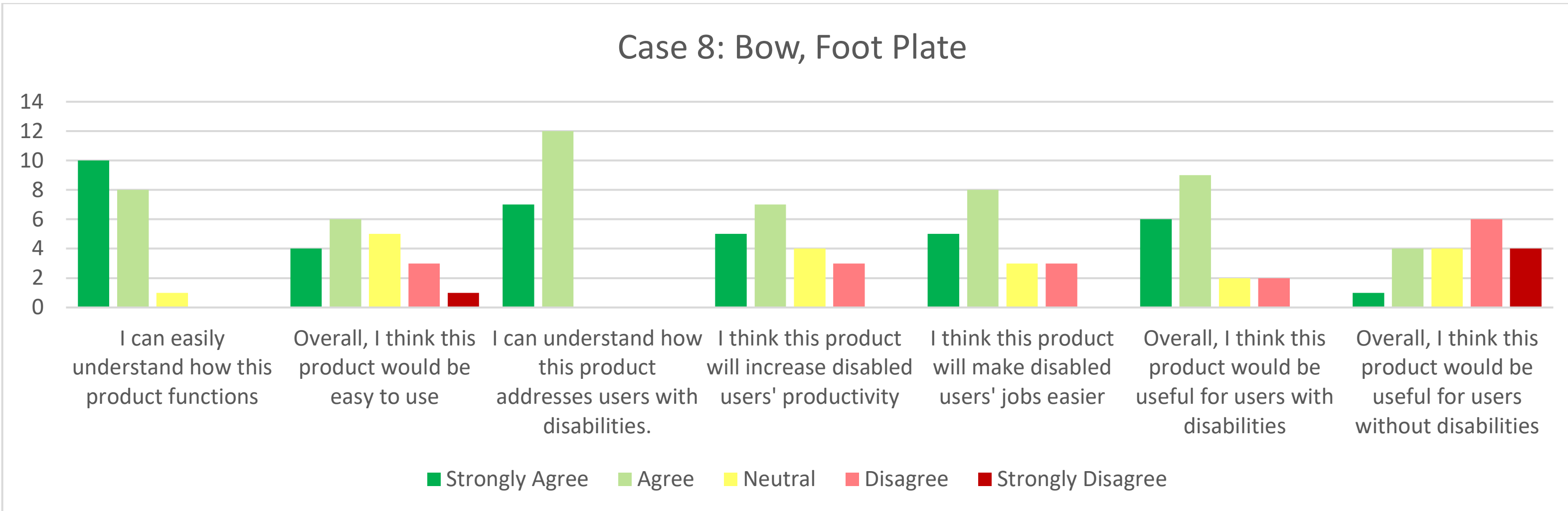
Totals:	I can easily understand how this product functions	Overall, I think this product would be easy to use	I can understand how this product addresses users with disabilities.	I think this product will increase disabled users' productivity	I think this product will make disabled users' jobs easier	Overall, I think this product would be useful for users with disabilities	Overall, I think this product would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	11	0	7	5	3	5	2	4
Agree	6	10	8	6	10	7	2	
Neutral	1	2	4	4	3	2	3	
Disagree	1	6	0	3	2	3	3	
Strongly Disagree	0	1	0	1	1	2	9	
Median	**5**	**4**	**4**	**4**	**4**	**4**	**2**	

Case 7: Ladder



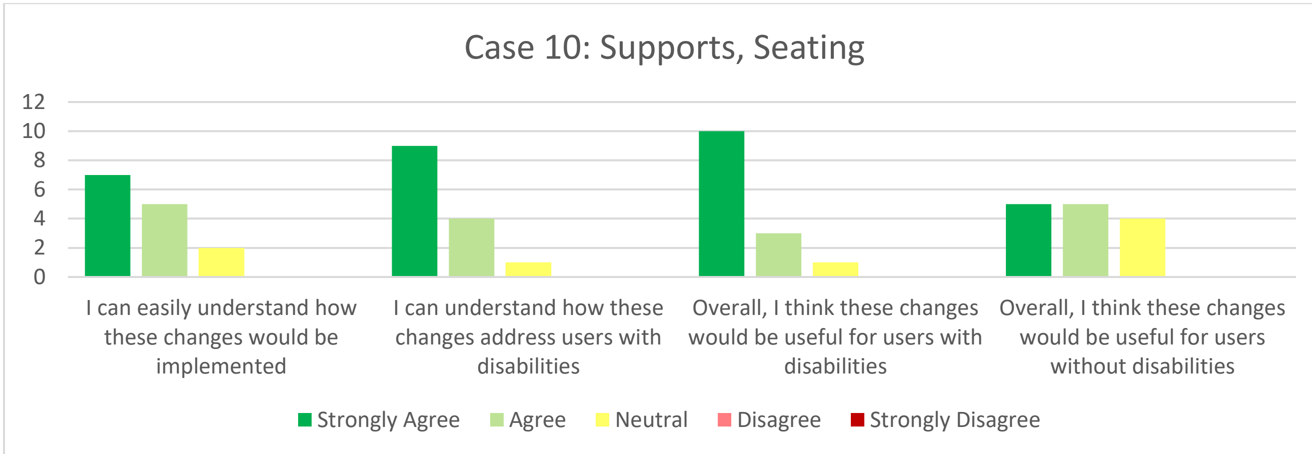
Totals:	I can easily understand how this product functions	Overall, I think this product would be easy to use	I can understand how this product addresses users with disabilities.	I think this product will increase disabled users' productivity	I think this product will make disabled users' jobs easier	Overall, I think this product would be useful for users with disabilities	Overall, I think this product would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	11	6	11	7	10	8	6	4
Agree	7	11	7	10	8	10	8	
Neutral	0	2	1	1	0	0	0	
Disagree	1	0	0	1	1	1	3	
Strongly Disagree	0	0	0	0	0	0	2	
Median of Questions	**5**	**4**	**5**	**4**	**5**	**4**	**4**	

Case 8: Bow, Foot Plate



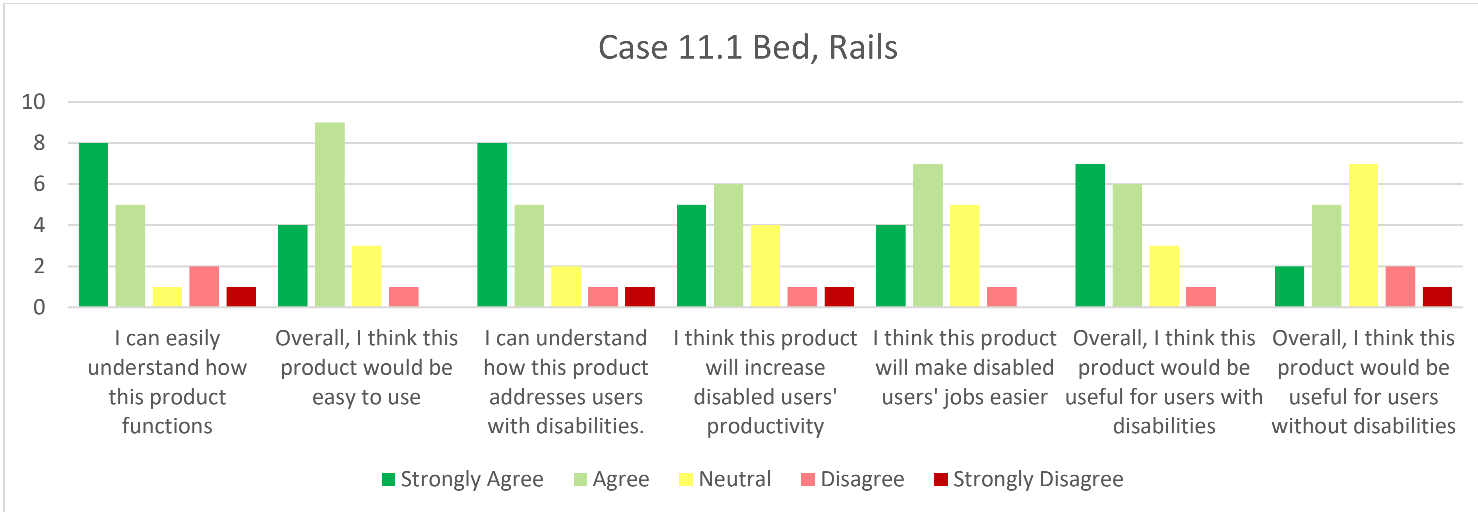
	I can easily understand how this product functions	Overall, I think this product would be easy to use	I can understand how this product addresses users with disabilities.	I think this product will increase disabled users' productivity	I think this product will make disabled users' jobs easier	Overall, I think this product would be useful for users with disabilities	Overall, I think this product would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	10	4	7	5	5	6	1	4
Agree	8	6	12	7	8	9	4	
Neutral	1	5	0	4	3	2	4	
Disagree	0	3	0	3	3	2	6	
Strongly Disagree	0	1	0	0	0	0	4	
Median of Questions	**5**	**4**	**4**	**4**	**4**	**4**	**2**	

Case 10: Supports, Seating



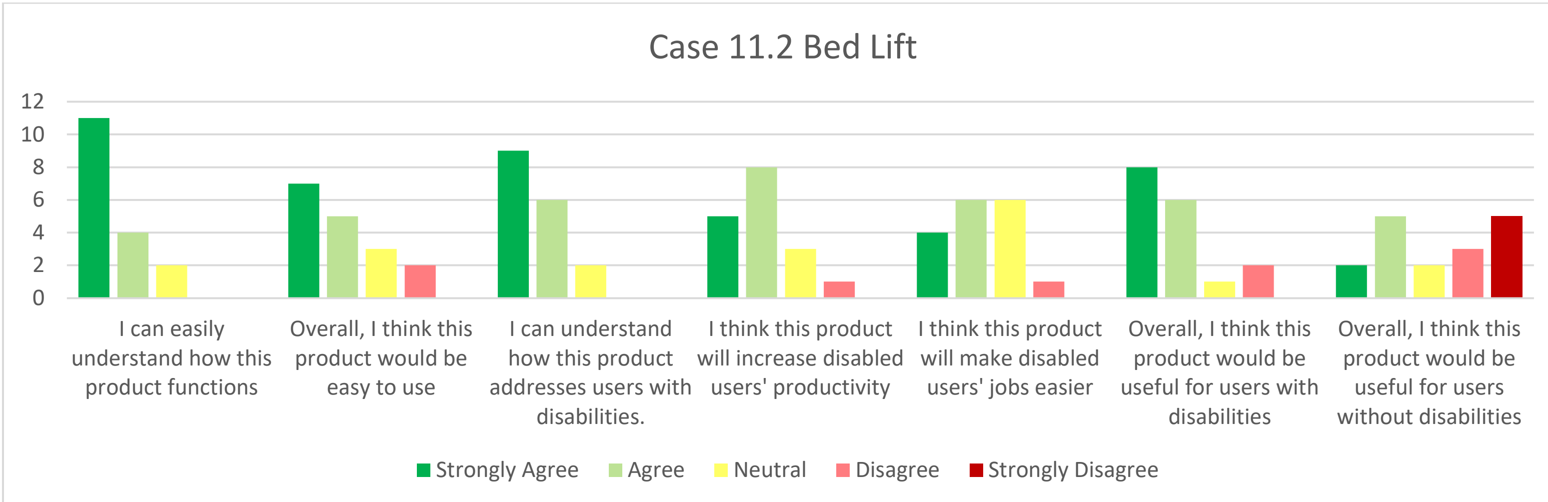
	I can easily understand how these changes would be implemented	I can understand how these changes address users with disabilities	Overall, I think these changes would be useful for users with disabilities	Overall, I think these changes would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	7	9	10	5	**5**
Agree	5	4	3	5	
Neutral	2	1	1	4	
Disagree	0	0	0	0	
Strongly Disagree	0	0	0	0	
Question Median	**4.5**	**5**	**5**	**4**	

Case 11.1: Bed Rotating Rails



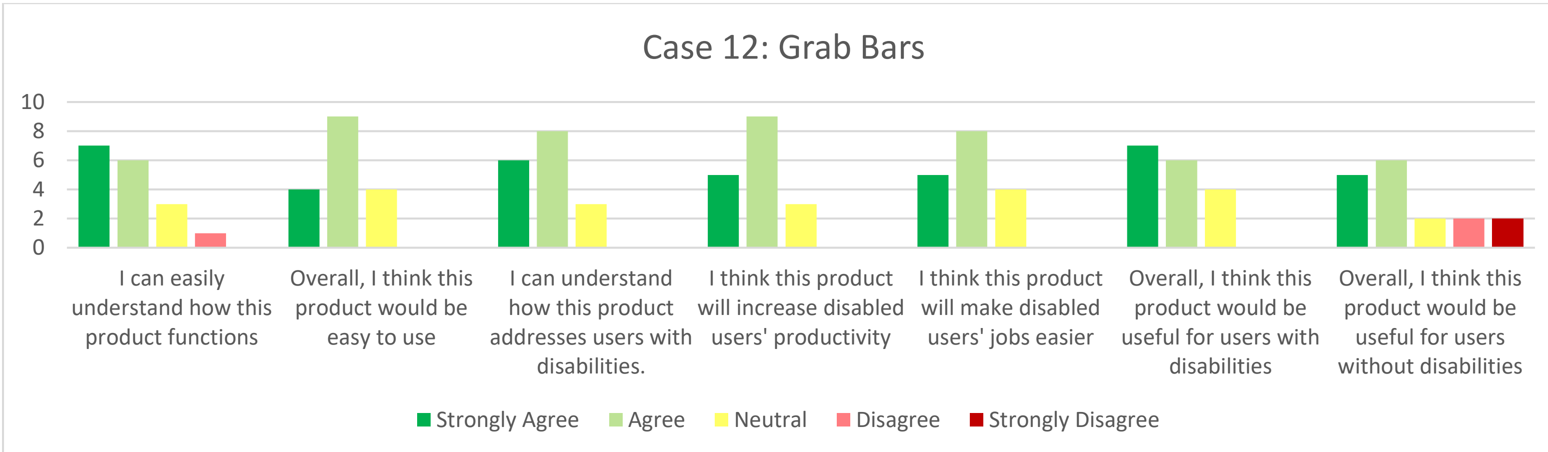
	I can easily understand how this product functions	Overall, I think this product would be easy to use	I can understand how this product addresses users with disabilities.	I think this product will increase disabled users' productivity	I think this product will make disabled users' jobs easier	Overall, I think this product would be useful for users with disabilities	Overall, I think this product would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	8	4	8	5	4	7	2	**4**
Agree	5	9	5	6	7	6	5	
Neutral	1	3	2	4	5	3	7	
Disagree	2	1	1	1	1	1	2	
Strongly Disagree	1	0	1	1	0	0	1	
Median Values	**4**	**4**	**4**	**4**	**4**	**4**	**3**	

Case 11.2: Bed, Hydraulic Lift



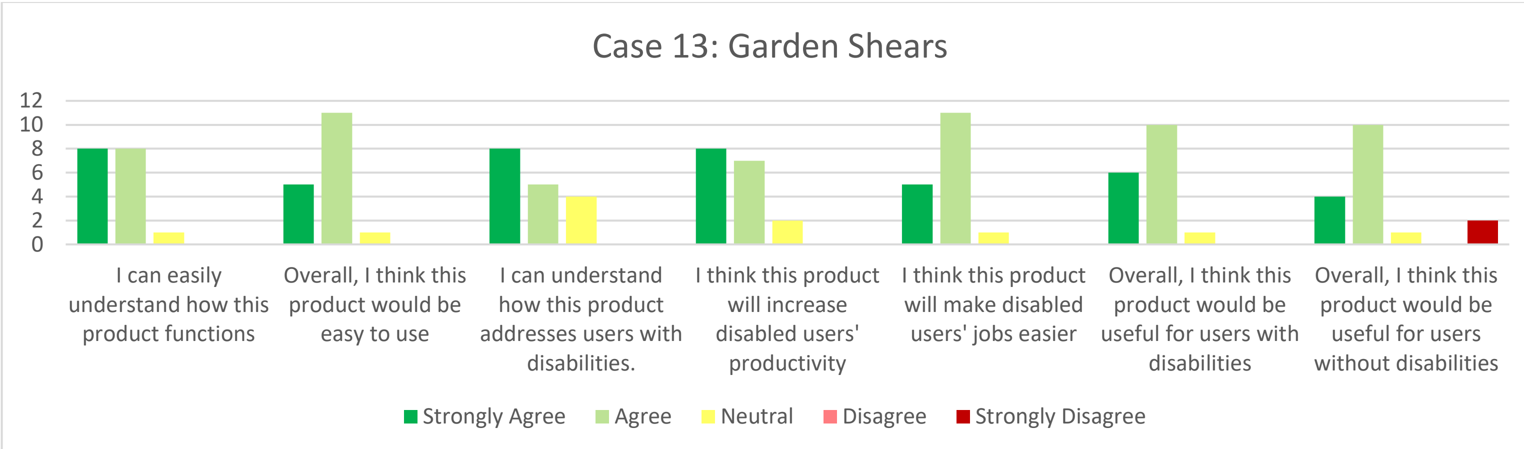
	I can easily understand how this product functions	Overall, I think this product would be easy to use	I can understand how this product addresses users with disabilities.	I think this product will increase disabled users' productivity	I think this product will make disabled users' jobs easier	Overall, I think this product would be useful for users with disabilities	Overall, I think this product would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	11	7	9	5	4	8	2	4
Agree	4	5	6	8	6	6	5	
Neutral	2	3	2	3	6	1	2	
Disagree	0	2	0	1	1	2	3	
Strongly Disagree	0	0	0	0	0	0	5	
Median Values	**5**	**4**	**5**	**4**	**4**	**4**	**3**	

Case 12: Grab Bars



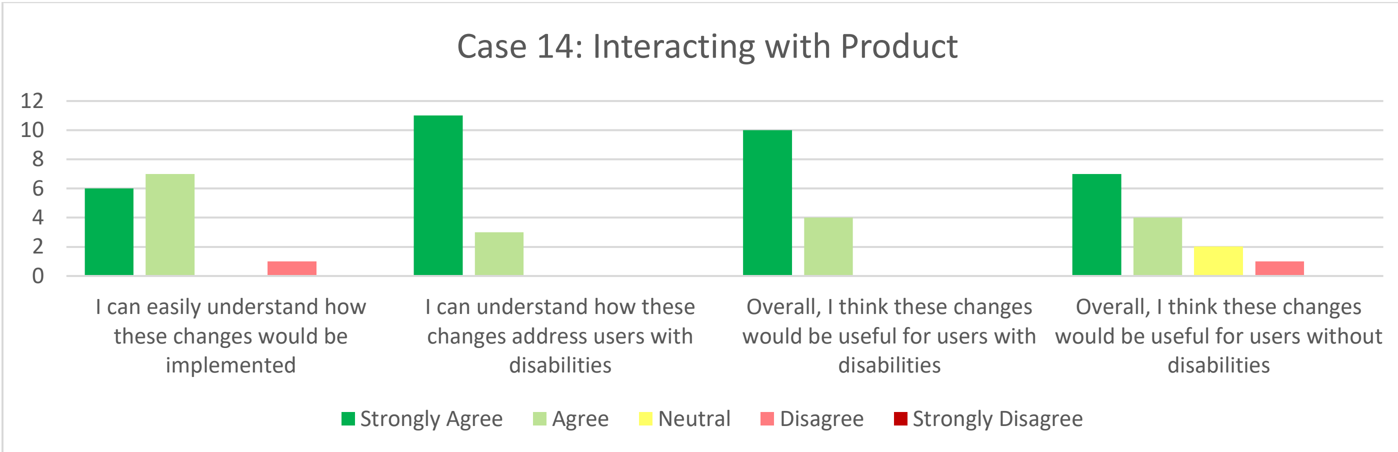
	I can easily understand how this product functions	Overall, I think this product would be easy to use	I can understand how this product addresses users with disabilities.	I think this product will increase disabled users' productivity	I think this product will make disabled users' jobs easier	Overall, I think this product would be useful for users with disabilities	Overall, I think this product would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	7	4	6	5	5	7	5	4
Agree	6	9	8	9	8	6	6	
Neutral	3	4	3	3	4	4	2	
Disagree	1	0	0	0	0	0	2	
Strongly Disagree	0	0	0	0	0	0	2	
Median Values	**4**	**4**	**4**	**4**	**4**	**4**	**4**	

Case 13: Garden Shears



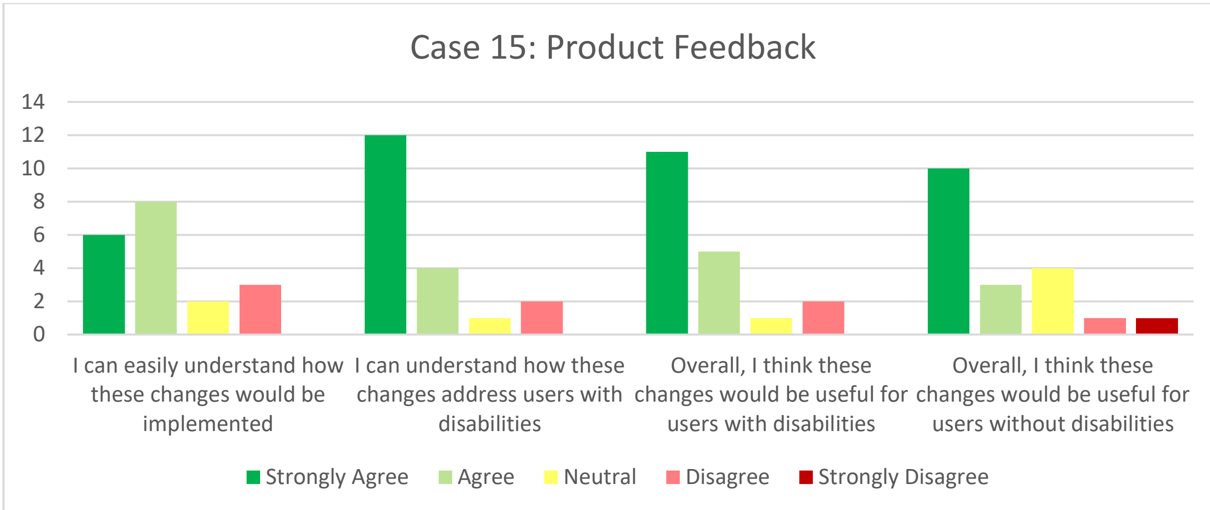
	I can easily understand how this product functions	Overall, I think this product would be easy to use	I can understand how this product addresses users with disabilities.	I think this product will increase disabled users' productivity	I think this product will make disabled users' jobs easier	Overall, I think this product would be useful for users with disabilities	Overall, I think this product would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	8	5	8	8	5	6	4	4
Agree	8	11	5	7	11	10	10	
Neutral	1	1	4	2	1	1	1	
Disagree	0	0	0	0	0	0	0	
Strongly Disagree	0	0	0	0	0	0	2	
Median Values	**4**	**4**	**4**	**4**	**4**	**4**	**4**	

Case 14: Interfacing with a Product



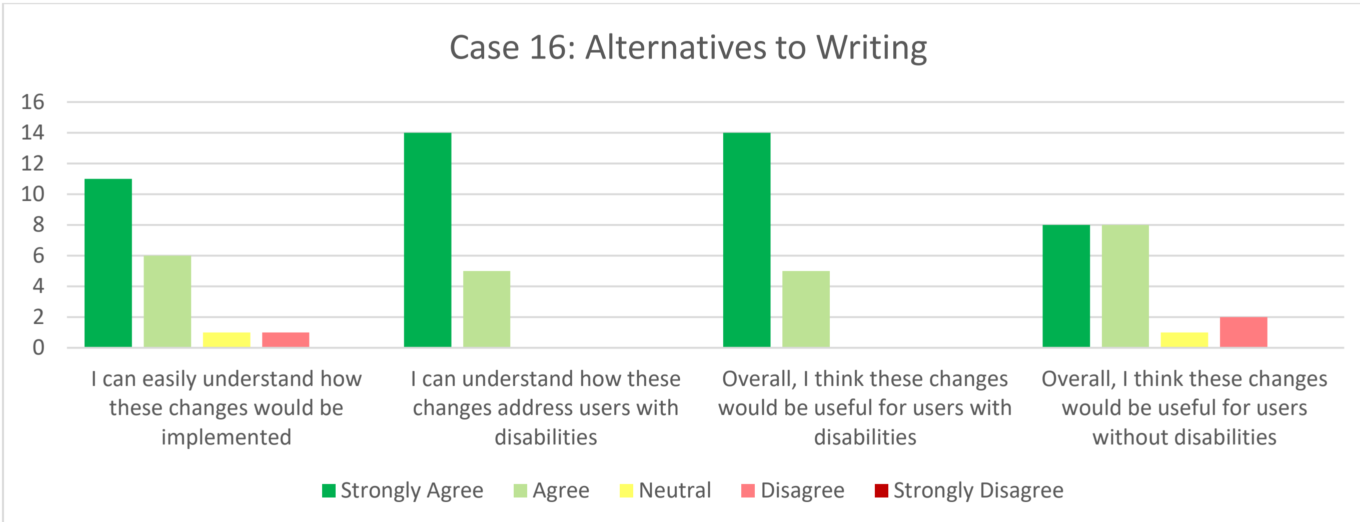
	I can easily understand how these changes would be implemented	I can understand how these changes address users with disabilities	Overall, I think these changes would be useful for users with disabilities	Overall, I think these changes would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	6	11	10	7	5
Agree	7	3	4	4	
Neutral	0	0	0	2	
Disagree	1	0	0	1	
Strongly Disagree	0	0	0	0	
Median of Questions	**4**	**5**	**5**	**4.5**	

Case 15: Product Feedback



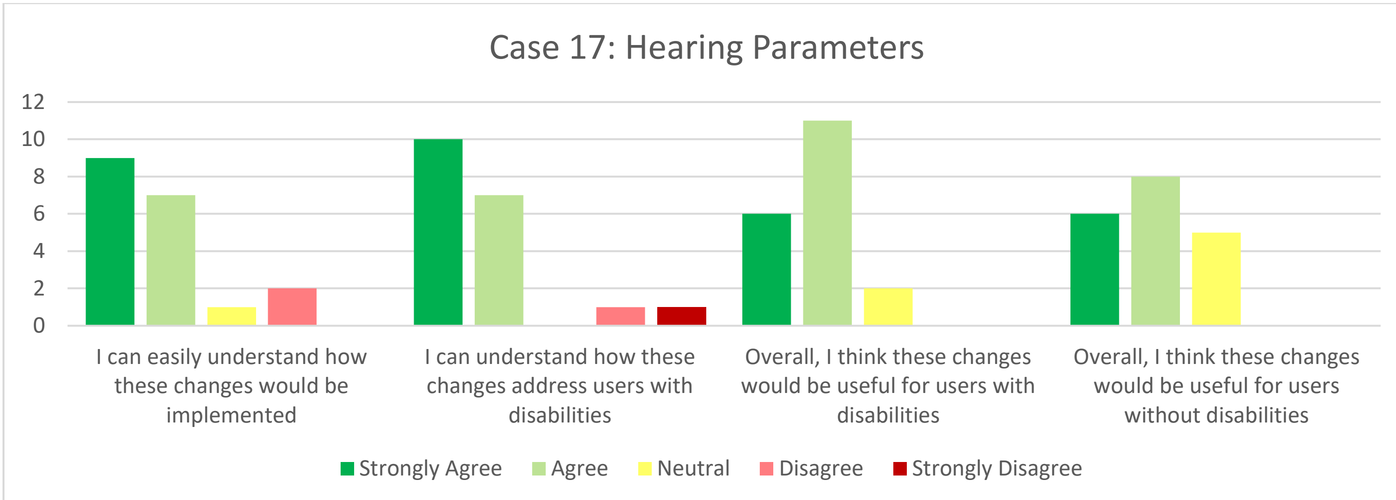
	I can easily understand how these changes would be implemented	I can understand how these changes address users with disabilities	Overall, I think these changes would be useful for users with disabilities	Overall, I think these changes would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	6	12	11	10	5
Agree	8	4	5	3	
Neutral	2	1	1	4	
Disagree	3	2	2	1	
Strongly Disagree	0	0	0	1	
Median of Questions	**4**	**5**	**5**	**5**	

Case 16: Alternatives to Writing



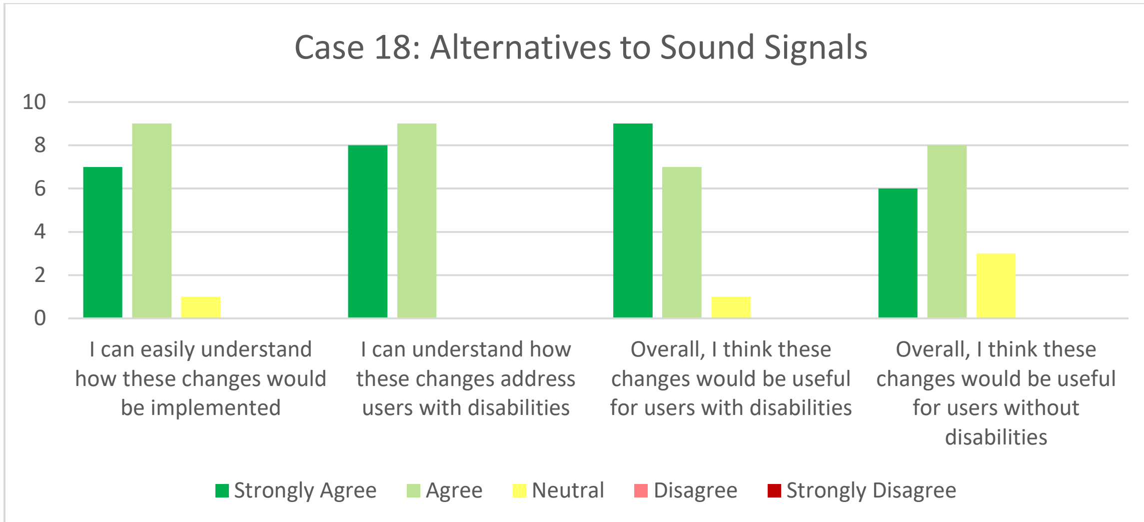
	I can easily understand how these changes would be implemented	I can understand how these changes address users with disabilities	Overall, I think these changes would be useful for users with disabilities	Overall, I think these changes would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	11	14	14	8	5
Agree	6	5	5	8	
Neutral	1	0	0	1	
Disagree	1	0	0	2	
Strongly Disagree	0	0	0	0	
Median of Questions	**5**	**5**	**5**	**4**	

Case 17: Hearing Parameters



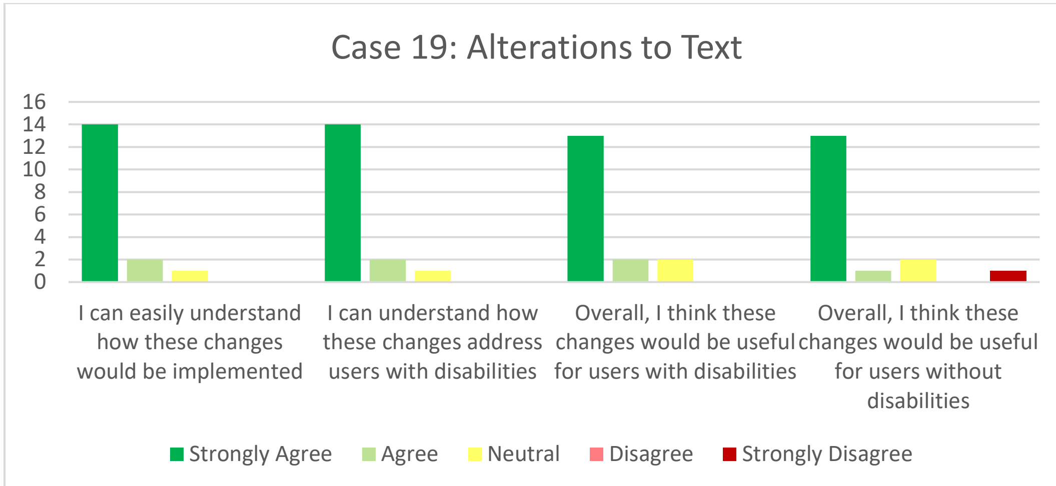
	I can easily understand how these changes would be implemented	I can understand how these changes address users with disabilities	Overall, I think these changes would be useful for users with disabilities	Overall, I think these changes would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	9	10	6	6	4
Agree	7	7	11	8	
Neutral	1	0	2	5	
Disagree	2	1	0	0	
Strongly Disagree	0	1	0	0	
Median of Questions	**4**	**5**	**4**	**4**	

Case 18: Alternatives to Sound Signals



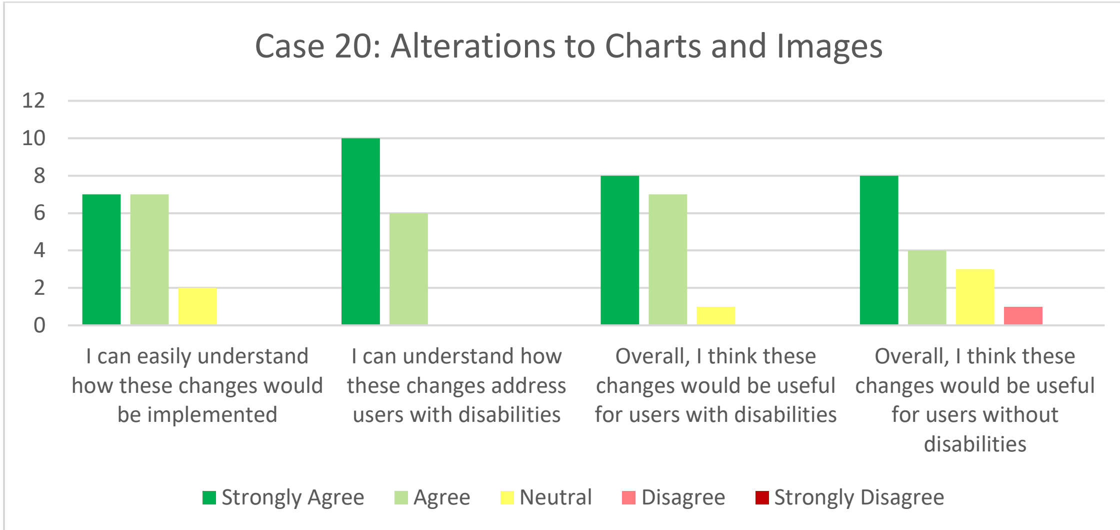
	I can easily understand how these changes would be implemented	I can understand how these changes address users with disabilities	Overall, I think these changes would be useful for users with disabilities	Overall, I think these changes would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	7	8	9	6	4
Agree	9	9	7	8	
Neutral	1	0	1	3	
Disagree	0	0	0	0	
Strongly Disagree	0	0	0	0	
Median Values	**4**	**4**	**5**	**4**	

Case 19: Alterations to Text



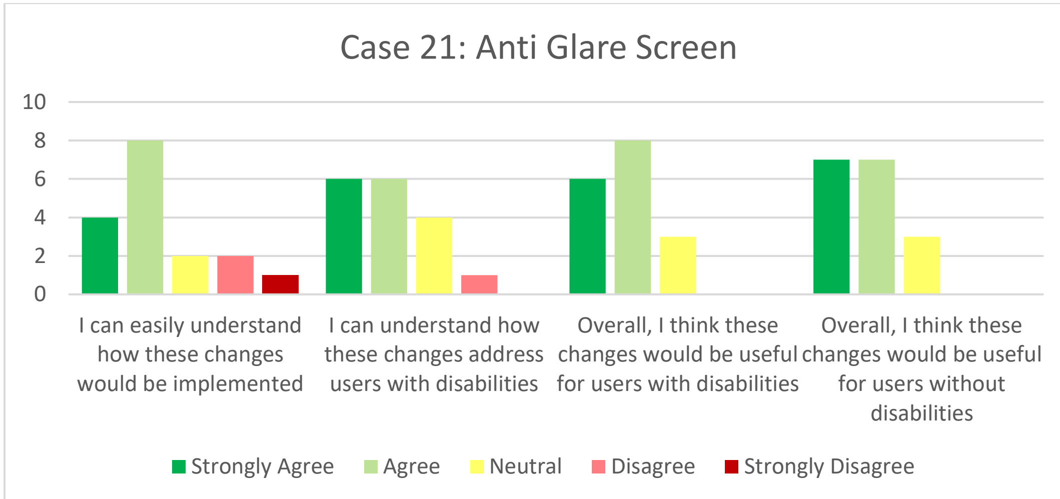
	I can easily understand how these changes would be implemented	I can understand how these changes address users with disabilities	Overall, I think these changes would be useful for users with disabilities	Overall, I think these changes would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	14	14	13	13	5
Agree	2	2	2	1	
Neutral	1	1	2	2	
Disagree	0	0	0	0	
Strongly Disagree	0	0	0	1	
Median Values	**5**	**5**	**5**	**5**	

Case 20: Alterations to Charts and Images



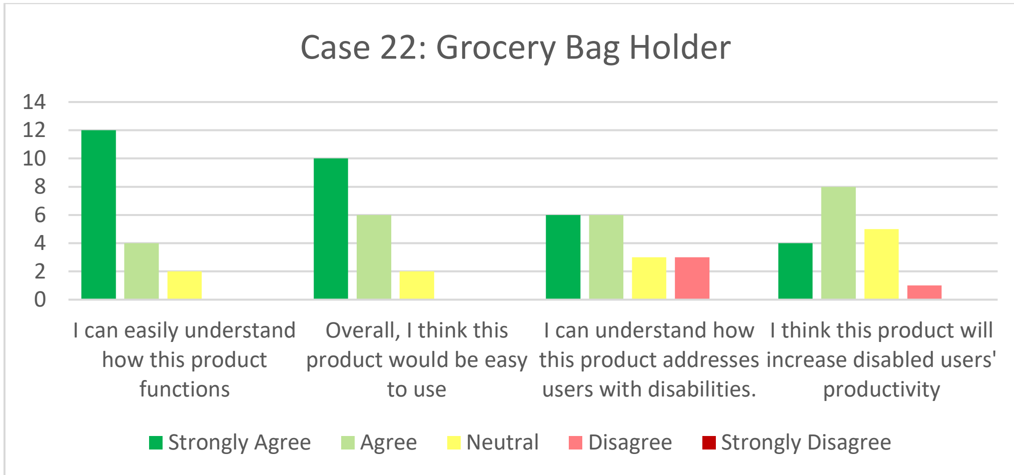
	I can easily understand how these changes would be implemented	I can understand how these changes address users with disabilities	Overall, I think these changes would be useful for users with disabilities	Overall, I think these changes would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	7	10	8	8	5
Agree	7	6	7	4	
Neutral	2	0	1	3	
Disagree	0	0	0	1	
Strongly Disagree	0	0	0	0	
Median Values	**4**	**5**	**4.5**	**4.5**	

Case 21: Anti-Glare Screen



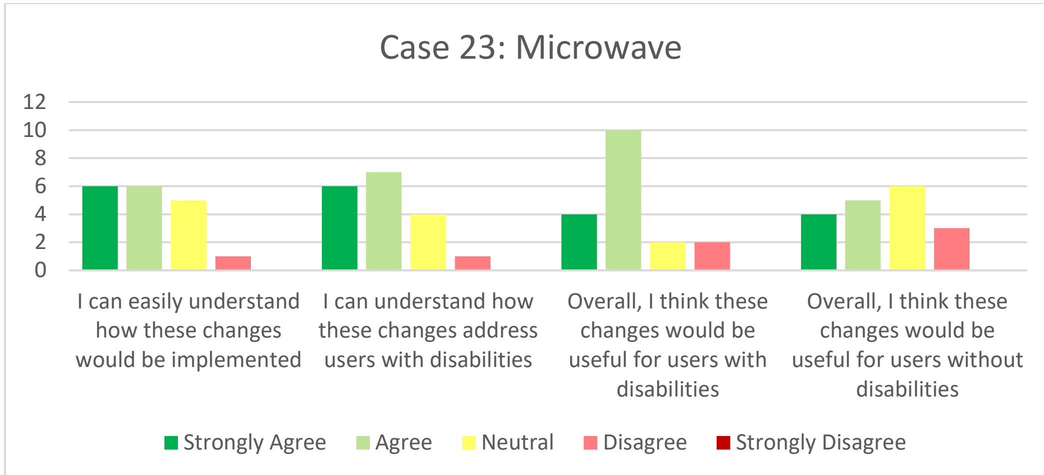
	I can easily understand how these changes would be implemented	I can understand how these changes address users with disabilities	Overall, I think these changes would be useful for users with disabilities	Overall, I think these changes would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	4	6	6	7	4
Agree	8	6	8	7	
Neutral	2	4	3	3	
Disagree	2	1	0	0	
Strongly Disagree	1	0	0	0	
Median Values	**4**	**4**	**4**	**4**	

Case 22: Grocery Bag Holder



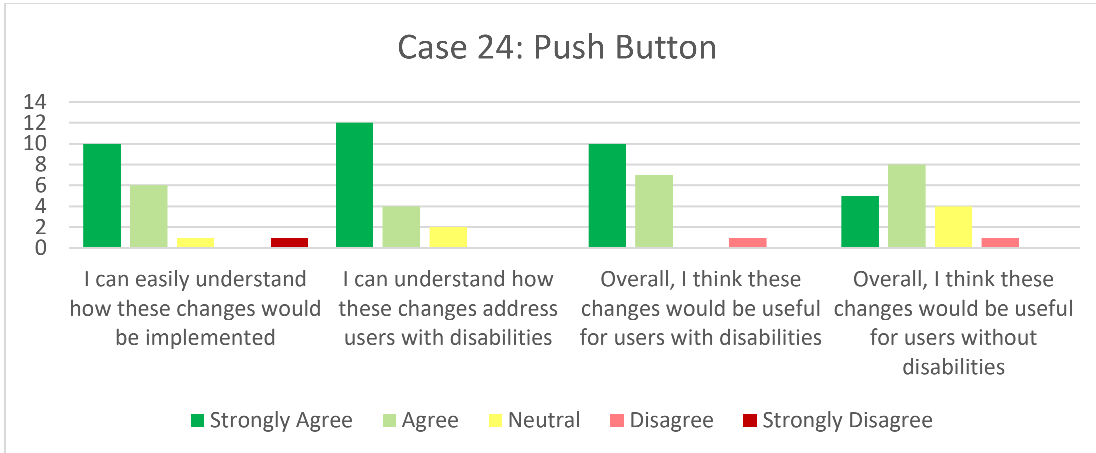
	I can easily understand how this product functions	Overall, I think this product would be easy to use	I can understand how this product addresses users with disabilities.	I think this product will increase disabled users' productivity	I think this product will make disabled users' jobs easier	Overall, I think this product would be useful for users with disabilities	Overall, I think this product would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	12	10	6	4	5	6	7	4
Agree	4	6	6	8	8	7	8	
Neutral	2	2	3	5	3	4	1	
Disagree	0	0	3	1	2	1	2	
Strongly Disagree	0	0	0	0	0	0	0	
Median Values	**5**	**5**	**4**	**4**	**4**	**4**	**4**	

Case 23: Microwave



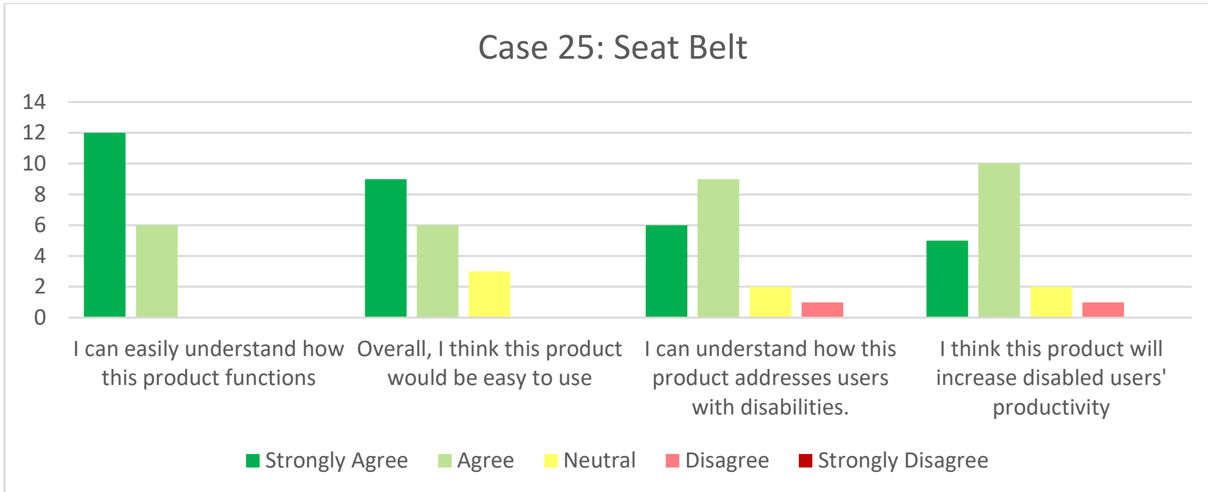
	I can easily understand how these changes would be implemented	I can understand how these changes address users with disabilities	Overall, I think these changes would be useful for users with disabilities	Overall, I think these changes would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	6	6	4	4	4
Agree	6	7	10	5	
Neutral	5	4	2	6	
Disagree	1	1	2	3	
Strongly Disagree	0	0	0	0	
Median Values	**4**	**4**	**4**	**3.5**	

Case 24: Push Button



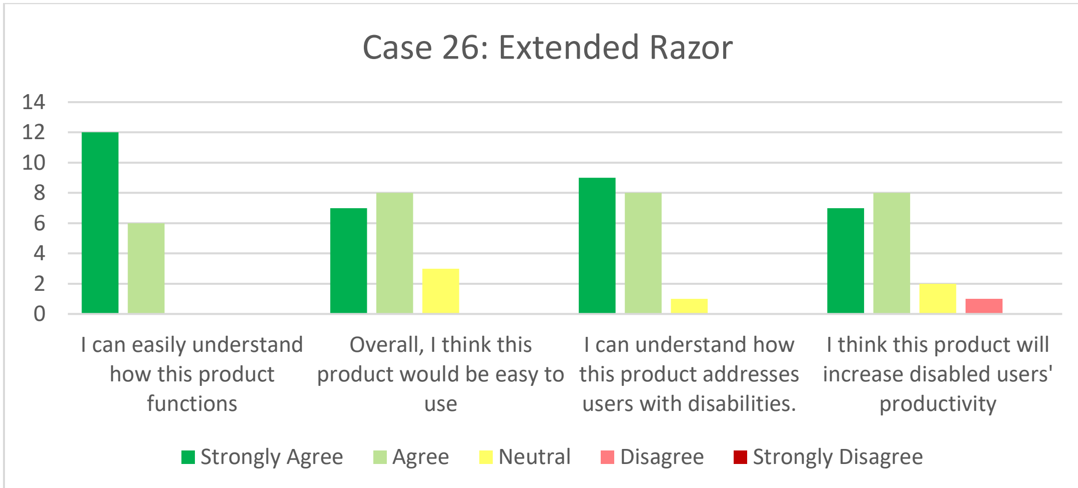
	I can easily understand how these changes would be implemented	I can understand how these changes address users with disabilities	Overall, I think these changes would be useful for users with disabilities	Overall, I think these changes would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	10	12	10	5	4.5
Agree	6	4	7	8	
Neutral	1	2	0	4	
Disagree	0	0	1	1	
Strongly Disagree	1	0	0	0	
Median Values	**5**	**5**	**5**	**4**	

Case 25: Seat Belt



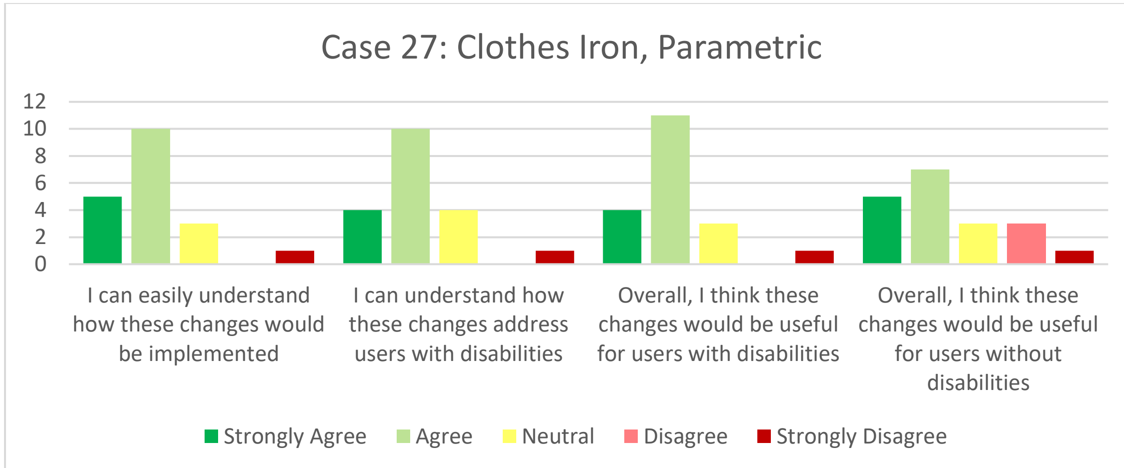
	I can easily understand how this product functions	Overall, I think this product would be easy to use	I can understand how this product addresses users with disabilities.	I think this product will increase disabled users' productivity	I think this product will make disabled users' jobs easier	Overall, I think this product would be useful for users with disabilities	Overall, I think this product would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	12	9	6	5	5	6	7	4
Agree	6	6	9	10	9	9	7	
Neutral	0	3	2	2	2	2	1	
Disagree	0	0	1	1	2	1	3	
Strongly Disagree	0	0	0	0	0	0	0	
Median Values	**5**	**4.5**	**4**	**4**	**4**	**4**	**4**	

Case 26: Extended Razor



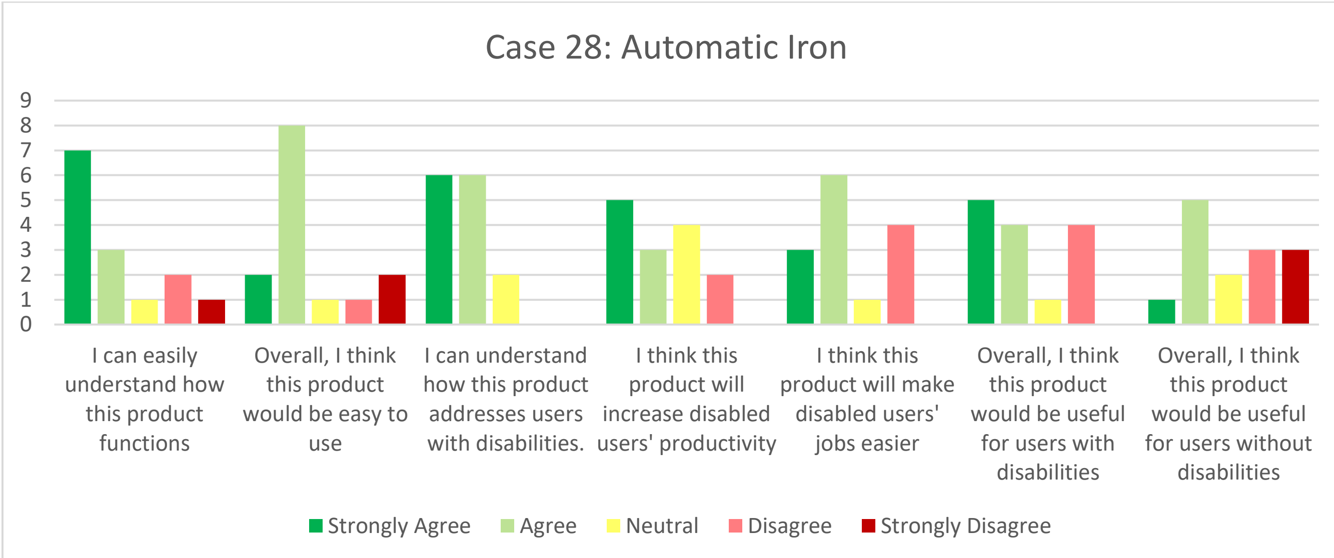
	I can easily understand how this product functions	Overall, I think this product would be easy to use	I can understand how this product addresses users with disabilities.	I think this product will increase disabled users' productivity	I think this product will make disabled users' jobs easier	Overall, I think this product would be useful for users with disabilities	Overall, I think this product would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	12	7	9	7	7	6	7	4
Agree	6	8	8	8	8	12	7	
Neutral	0	3	1	2	3	0	3	
Disagree	0	0	0	1	0	0	1	
Strongly Disagree	0	0	0	0	0	0	0	
Median Values	**5**	**4**	**4.5**	**4**	**4**	**4**	**4**	

Case 27: Clothes Iron, Parametric



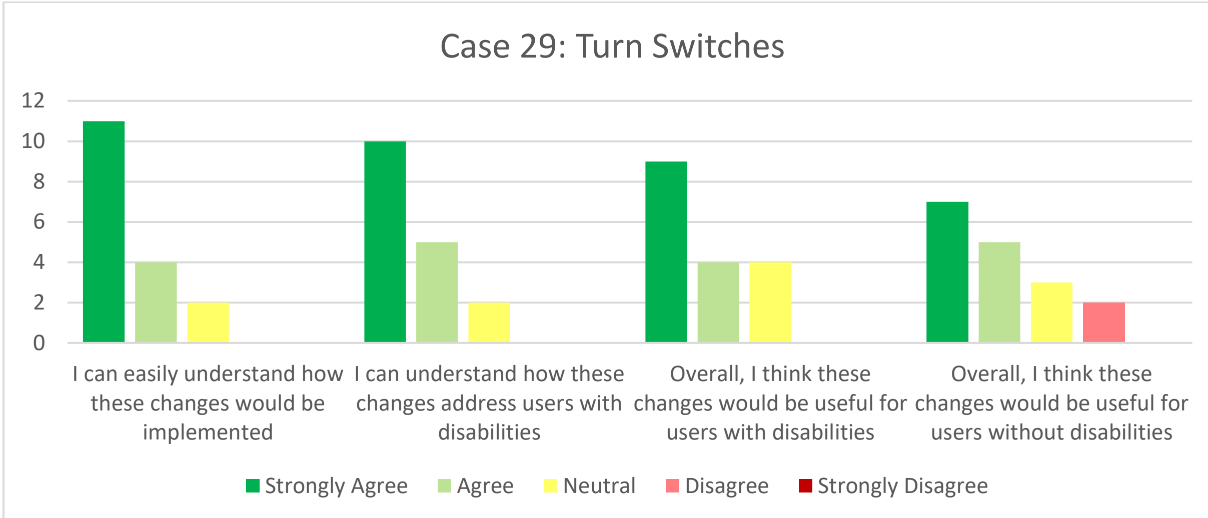
	I can easily understand how these changes would be implemented	I can understand how these changes address users with disabilities	Overall, I think these changes would be useful for users with disabilities	Overall, I think these changes would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	5	4	4	5	4
Agree	10	10	11	7	
Neutral	3	4	3	3	
Disagree	0	0	0	3	
Strongly Disagree	1	1	1	1	
Median Values	**4**	**4**	**4**	**4**	

Case 28: Clothes Iron, Automatic



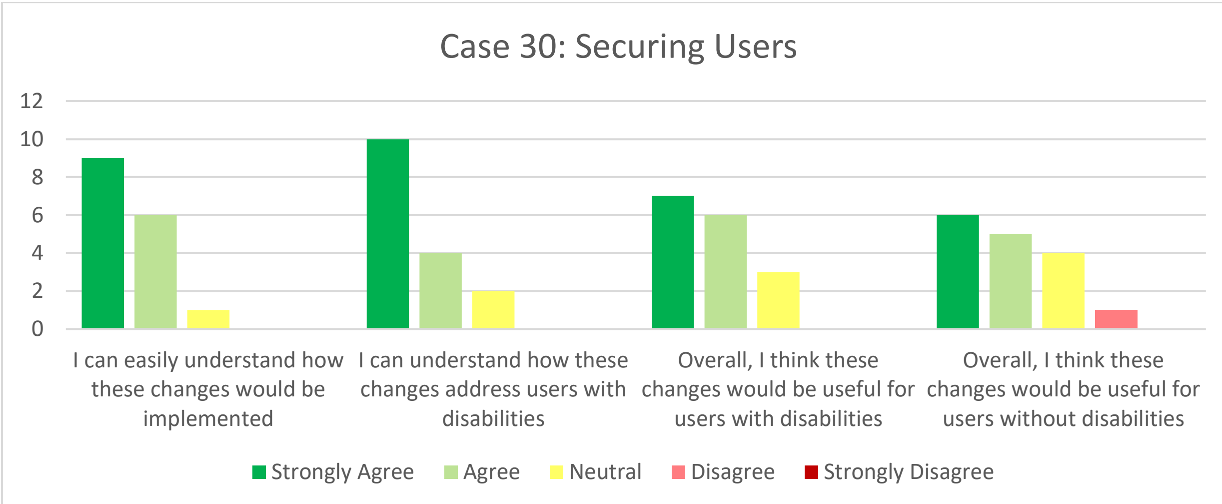
	I can easily understand how this product functions	Overall, I think this product would be easy to use	I can understand how this product addresses users with disabilities.	I think this product will increase disabled users' productivity	I think this product will make disabled users' jobs easier	Overall, I think this product would be useful for users with disabilities	Overall, I think this product would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	7	2	6	5	3	5	1	4
Agree	3	8	6	3	6	4	5	
Neutral	1	1	2	4	1	1	2	
Disagree	2	1	0	2	4	4	3	
Strongly Disagree	1	2	0	0	0	0	3	
Question Median	**4.5**	**4**	**4**	**4**	**4**	**4**	**3**	

Case 29: Turn Switches



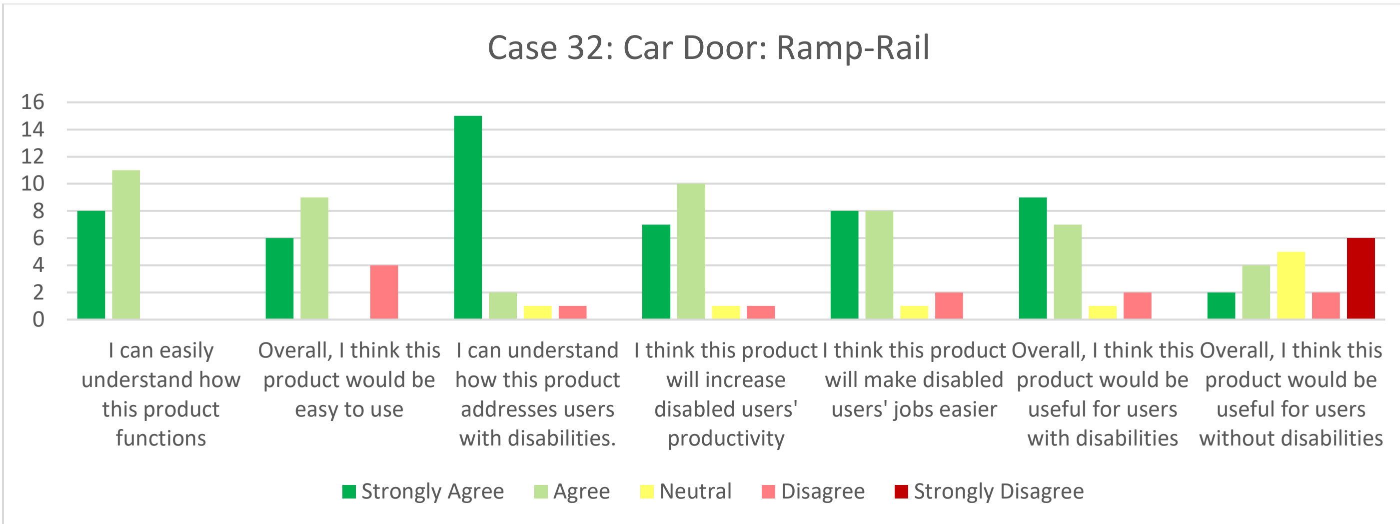
	I can easily understand how these changes would be implemented	I can understand how these changes address users with disabilities	Overall, I think these changes would be useful for users with disabilities	Overall, I think these changes would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	11	10	9	7	5
Agree	4	5	4	5	
Neutral	2	2	4	3	
Disagree	0	0	0	2	
Strongly Disagree	0	0	0	0	
Median Values	**5**	**5**	**5**	**4**	

Case 30: Securing Users, Rails



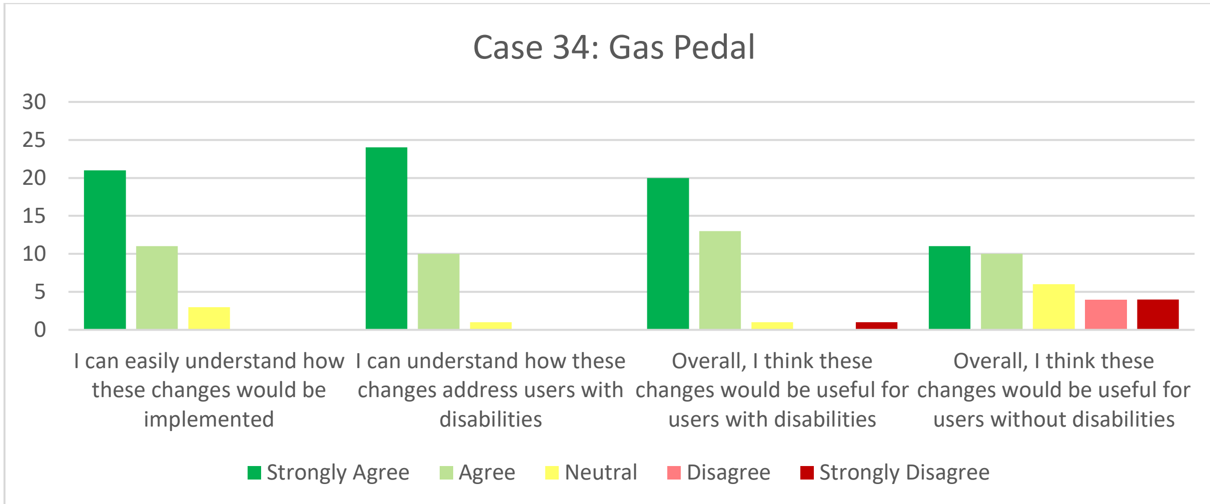
	I can easily understand how these changes would be implemented	I can understand how these changes address users with disabilities	Overall, I think these changes would be useful for users with disabilities	Overall, I think these changes would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	9	10	7	6	4
Agree	6	4	6	5	
Neutral	1	2	3	4	
Disagree	0	0	0	1	
Strongly Disagree	0	0	0	0	
Median Values	**5**	**5**	**4**	**4**	

Case 32: Car Door, Ramp-Rail



	I can easily understand how this product functions	Overall, I think this product would be easy to use	I can understand how this product addresses users with disabilities.	I think this product will increase disabled users' productivity	I think this product will make disabled users' jobs easier	Overall, I think this product would be useful for users with disabilities	Overall, I think this product would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	8	6	15	7	8	9	2	4
Agree	11	9	2	10	8	7	4	
Neutral	0	0	1	1	1	1	5	
Disagree	0	4	1	1	2	2	2	
Strongly Disagree	0	0	0	0	0	0	6	
Question Median	**4**	**4**	**5**	**4**	**4**	**4**	**3**	

Case 34: Gas Pedal, Joystick



	I can easily understand how these changes would be implemented	I can understand how these changes address users with disabilities	Overall, I think these changes would be useful for users with disabilities	Overall, I think these changes would be useful for users without disabilities	**Perceived Inclusivity**
Strongly Agree	21	24	20	11	5
Agree	11	10	13	10	
Neutral	3	1	1	6	
Disagree	0	0	0	4	
Strongly Disagree	0	0	1	4	
Median of Questions	**5**	**5**	**5**	**4**	

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APPENDIX G: VALIDATION STUDY QUESTIONS

Product Redesigns – Application of Inclusive Design Rules

Study Design and Procedures:

Participants will be asked to complete an assignment involving the application of design rules to given products. Participants will first be given an introduction on the field of inclusive design in the form of a lecture on universal design principles, actionfunction diagrams, and inclusive design rules and their applications. Participants will be given the same products from IRB 2016-0442D to redesign using given inclusive design rules. During the redesign process, participants will need to identify applicable design rules from the given set, and apply the chosen rules to the product actionfunction diagram. Participants will then develop a physical representation and description of their modified product. After this procedure, the participants' designed products will be reviewed by an expert in inclusive design. At the conclusion of their questionnaire, participants will be asked general feedback questions on the actionfunction diagram + inclusive design rule process. Participants will be given 5-6 of these aforementioned product redesign questions.

Universal (or Inclusive) Design:

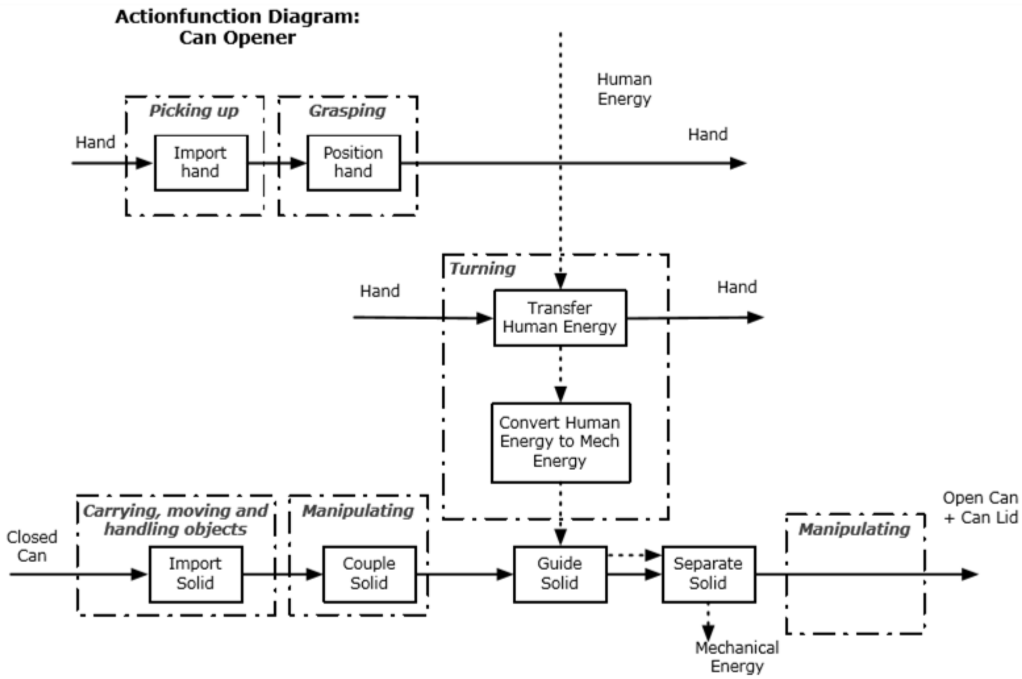
Universal design is the engineering practice to develop products and environments in such a way that they can be used effectively by all users, regardless of their ability level. Researchers also refer to universal design as accessible design, design for disability, or inclusive design. Universal design can be practiced on any product or environment. In order to best design a product for universal use, one must consider the demands on a user's capabilities. Any user who cannot meet the capabilities demanded by a certain product is severely limited in, if not excluded entirely from, its use. In order to include the widest possible range of users, designers should develop products with user capabilities in mind.

Inclusive Design Rules:

Research into the field of inclusive design has yielded a form of design rule, that when applied to a functional model of a product, results in suggested changes that would make the product more inclusive. These design rules have been developed by analyzing the relationships between typical (or non-inclusive) products and their inclusive counterparts. Additionally, more design rules can be added to this set by translating design guidelines from different formats into the design rule format. The purpose of this survey is to test the results of applying these design rules. These design rules are given in table form alongside the given design questions.

Problem Descriptions:

Each of the following problems will provide a typical product and its actionfunction diagram. An actionfunction diagram is a combination of a function structure and the associated user activities with each function (an example is provided below). Each problem also has a definition of relevant ICF user activity terminology.



Actionfunction Model of Typical Can Opener

In addition, design rules have been provided to aid in the design process. These rules take the form: (Typical Product Function, Typical User Activity) → (Required Change to Function in Order to Make More Inclusive). These rules are meant to be applied to the typical product actionfunction diagram.

The changes are classified as parametric, morphological, and functional changes. A functional difference between a typical and a universal indicates the addition or deletion of a product function. A morphological difference indicates the two products retain the same functionality, but have a different physical solution. A parametric difference refers to two products that have the same set of parameters, but a differing value for some parameter.

Each problem asks you to identify and apply relevant design rules to the typical product actionfunction diagram, and then to provide a physical representation or sketch of the product. Please be sure that your inclusive designs are based off of applying the design rules and not prior knowledge of a preexisting inclusive design. Also, please provide written descriptions of the changes you envision.

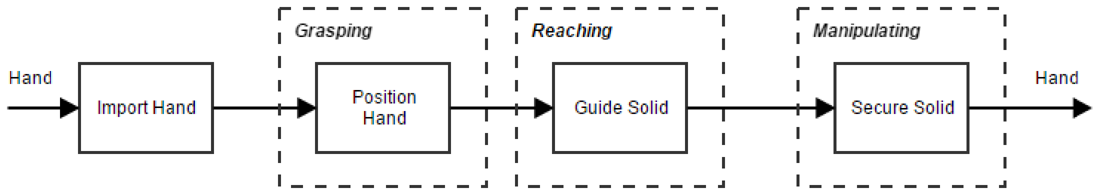
User Activity	Product Function	Recommended Change	User Activity Change
Dexterity			
Carrying, Moving, And Handling Objects	Transfer Human Energy	Functional	Easier, lower force
Carrying, moving and handling objects	Import Solid	No change	*Same as Typical*
Carrying, moving and handling objects	Position Hand	Parametric	Easier
Carrying, moving and handling objects	Position Solid	Parametric	Easier
Grasping	Position Hand	Parametric	Easier
Grasping	Secure Hand	Functional	Easier
Grasping	Position Hand	Morphological	Easier
Manipulating	Guide Solid	Morphological	Easier, one application of force
Manipulating	Actuate Signal	Morphological	Pushing with fingers
Manipulating	Guide Solid	Parametric	Easier
Manipulating	Position Hand	Parametric	Easier
Manipulating	Couple Solid	Parametric	Easier
Pulling	Guide Solid	Parametric	Easier
Pulling	Guide Solid	Morphological	No activity
Pushing with hand	Guide Solid	Parametric	Same as typical
Pushing with fingers	Guide Solid	Parametric	Same as typical
Turning	Guide Solid	Morphological	Pushing with hand
Turning	Regulate Electrical Energy	Parametric	Pushing with fingers
Reach And Stretch			
Reaching	Position Hand	Morphological	Reach with single arm
Reaching	Position Hand	Parametric	Easier
Reaching	Guide Solid	Morphological	Not exerting force with arm outstretched
Locomotion			
Bending	Interface With Product	Morphological	No bending over
Changing Basic Body Position	Support Human	Functional	Grasping with hand
Maintain Body Position	Position Human	Parametric	Easier
Moving Around	Import Human	Parametric	Easier
Moving Around	Support Human	Functional	Add in seating
Moving Around	Support Human	Morphological	Aesthetically better
Moving around	Secure Human	Functional	Better
Pushing with lower extremities	Guide Solid	Morphological	Pushing with hand
Sitting	Guide Human	Functional	Better, grasping with hand
Standing	Guide Human	Functional	Better, grasping with hand
Transferring oneself	Import Human	Morphological	Better
Transferring oneself	Import Human	Parametric	Easier
Communication			
Perceptual Functions	Interface With Product	Morphological	Easier
Perceptual Functions	Indicate Status	Functional	Easier
Perceptual Functions	Indicate Status	Morphological	Communication - various
Hearing			
Hearing functions	Indicate Status	Parametric	Easier
Hearing functions	Indicate Status	Morphological	Easier
Hearing Functions	Export Signal	Parametric	Adjust volume/frequency
Hearing Functions	Adjust Signal	Functional	Adjustable Volume
Hearing Functions	Export Signal	Morphological	Easier, Natural Voice

User Activity	Product Function	Recommended Change	User Activity Change
Hearing Functions	Export Signal	Morphological	Communication - various
Vision			
Communication - Written	Indicate Status	Parametric	Easier
Communication written	Indicate Status	Morphological	Communication Braille
Communication - Nonverbal	Indicate Status	Parametric	Easier
Seeing functions	Indicate Status	Parametric	Easier
Seeing Functions	Indicate Status	Morphological	Easier, reduce glare

Group One

Case 1: Fitted Bed Sheets

Users with diminished hand strength or dexterity, either due to age or injury, have trouble grasping products. Because they lack the necessary hand strength, users with impairments of the hand may not be able to maintain their grip on certain products as the user operates the product. In this case we consider the typical fitted bed sheet. In order to properly install the bed sheet, users must push and pull the sheet's edges around their mattress. Because fitted bed sheets contain elastic portions, it may be difficult for impaired

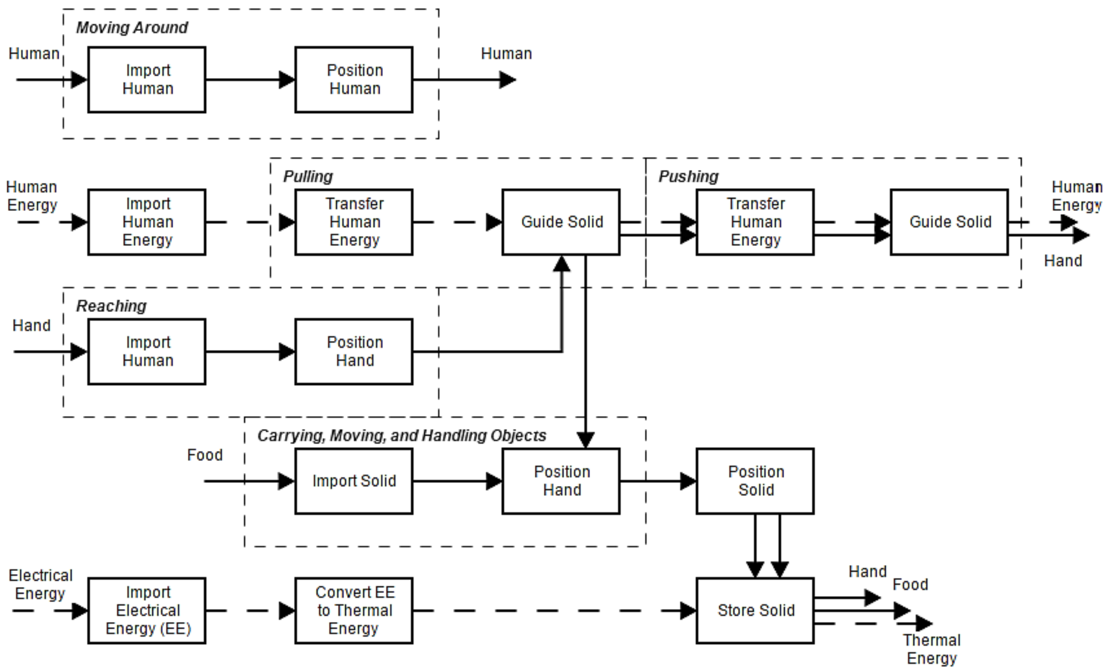


users to pull the sheet after they have secured one or more corners. The actionfunction diagram for a typical bed sheet is shown below:

Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the fitted sheets as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Case 2: Refrigerator Door Latch

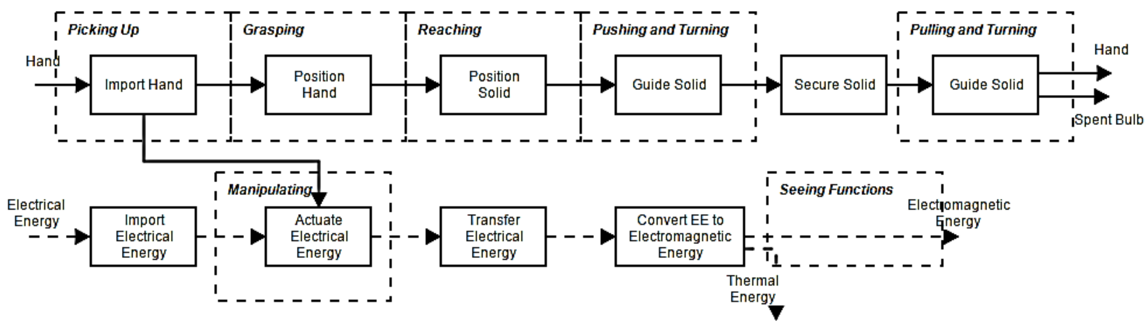
Consider the typical refrigerator. Users with diminished strength may find the force requirements too high for breaking the seal and opening the refrigerator door. Refrigerator door seals are generally tight due to magnetic strips as well as the pressure differential between the cool air inside and the warm air outside. While users may still be able to open the door through considerable application of their force, it could be beneficial for designers to develop a more easy to open refrigerator for persons suffering from arthritis, injuries, or other debilitating conditions. The actionfunction diagram for a refrigerator is provided below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the refrigerator as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Case 3: Light Bulb

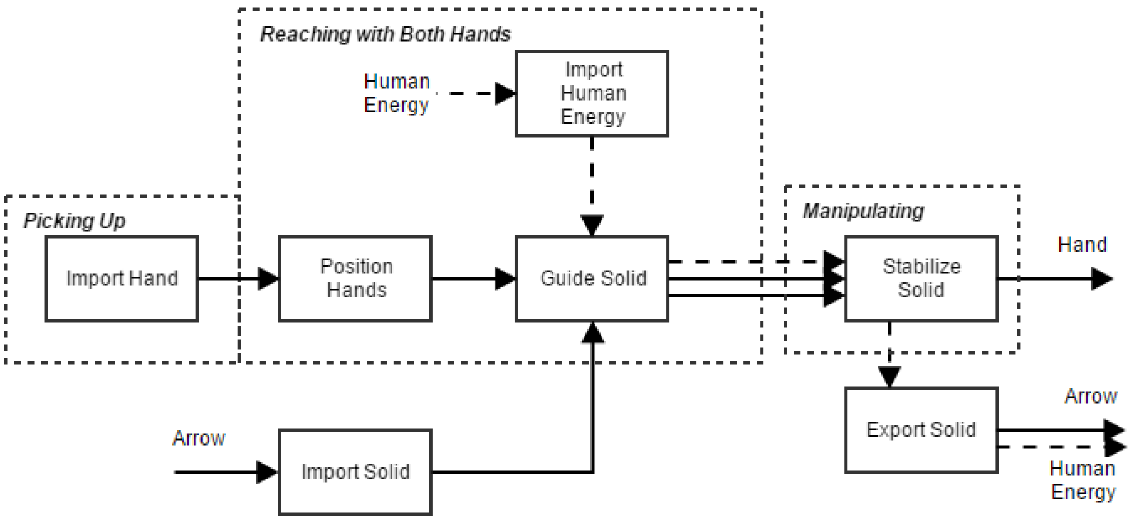
Users with diminished hand strength may have difficulties performing activities that require simultaneous manipulations. A classic example of a product that requires simultaneous manipulations is the child-proof pill bottle cap, which requires users to push and twist at the same time to disengage the cap. Many users have difficulty opening a pill bottle, which has led to many inclusive design alternatives, such as arthritis-friendly bottle caps. A lesser considered product that requires simultaneous manipulations is a lightbulb, as users must push and turn the lightbulb in order to install it. The actionfunction diagram for a light bulb is provided below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the light bulb as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Case 6: Bow

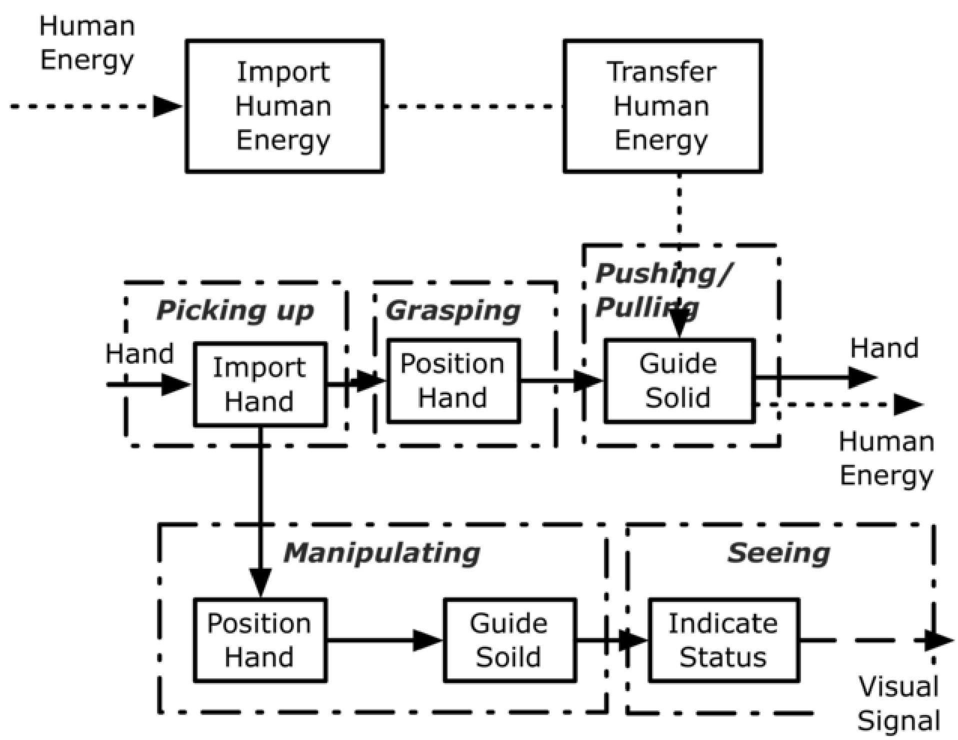
In order to make products more inclusive, designers should allow for users to operate products with a single hand, rather than two. Consider the following actionfunction diagram of a typical bow. In using a typical bow, users must exert force with both arms to draw and steady the bow. Apply the corresponding design rule and develop a physical representation of the resulting product. The typical bow actionfunction diagram is provided below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bow as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Case 28: Clothes Iron

Designers should consider users with upper body disabilities, or otherwise reduced upper body strength, when developing products that require the user to pull and guide some portion of the product. By enacting some change, designers can alter the product so that the moving parts are no longer associated with a user activity, and are instead accomplished by the product itself. Consider a typical iron, for which the actionfunction diagram is provided below.



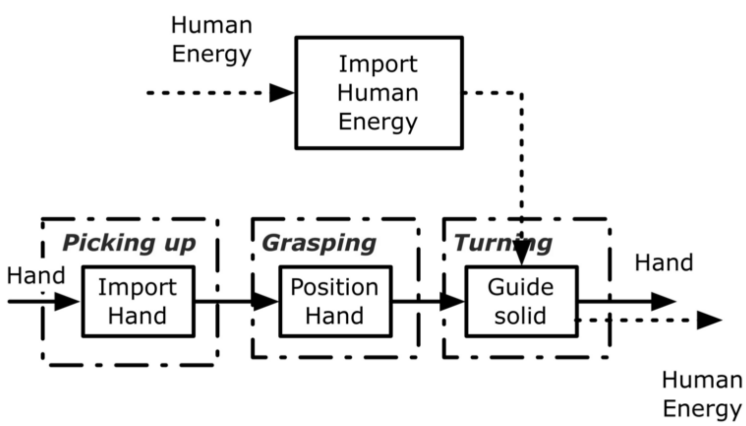
Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the clothes iron as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Group Two

Case 4: Bottle Cap

Users with diminished dexterity may have difficulties utilizing a pincer grip to grasp objects, as is necessary when turning an object. Designers should consider modifying products that require turning to instead utilize a different user activity. A classic example of a product that requires gripping and turning is a twist-off bottle cap, such as one would find on a plastic water bottle. The actionfunction diagram for a plastic water bottle cap is pictured below.

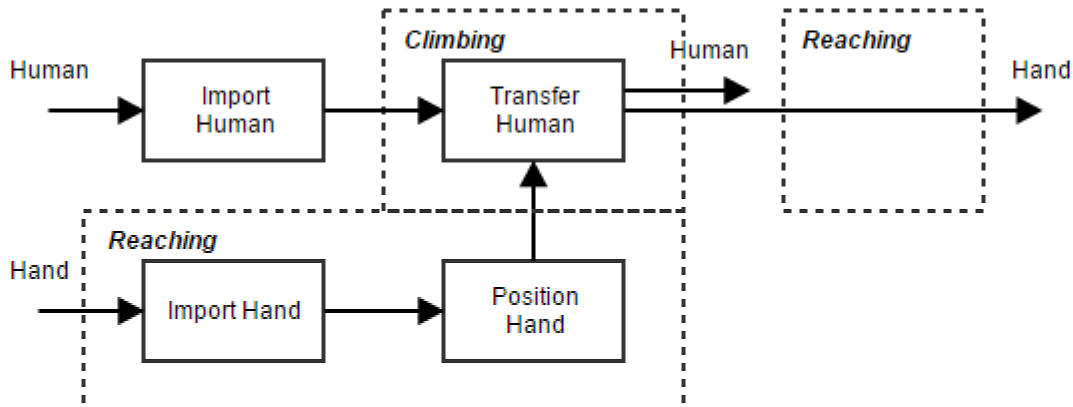
Typical bottle caps are threaded onto a receiving thread on the bottle, a cheap and reusable way of sealing the bottle. In developing a more inclusive product, we must also consider the marketability of the resulting product. Any new inclusive design should avoid increasing the cost or complexity of the system, so as to not inhibit its use.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bottle cap as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Case 7: Typical Ladder

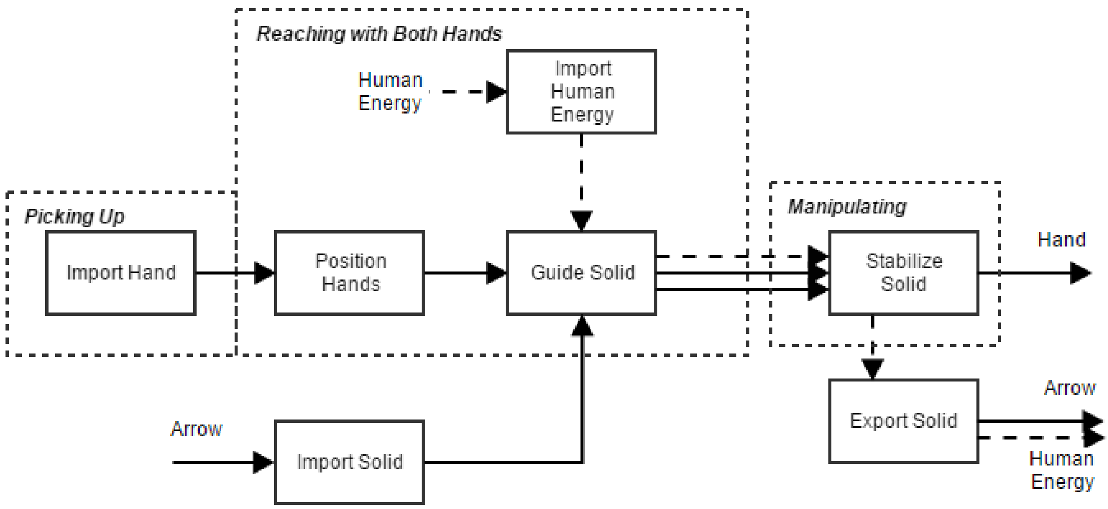
Users with physical impairments may have reduced reach when compared to able users. Consider the typical ladder, which requires users to reach and exert force with outstretched arms when climbing. In order to make the ladder more inclusive, modifications should allow users to scale the ladder regardless of their reach capabilities. The actionfunction diagram for a typical ladder is pictured below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the typical ladder as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Case 8: Bow

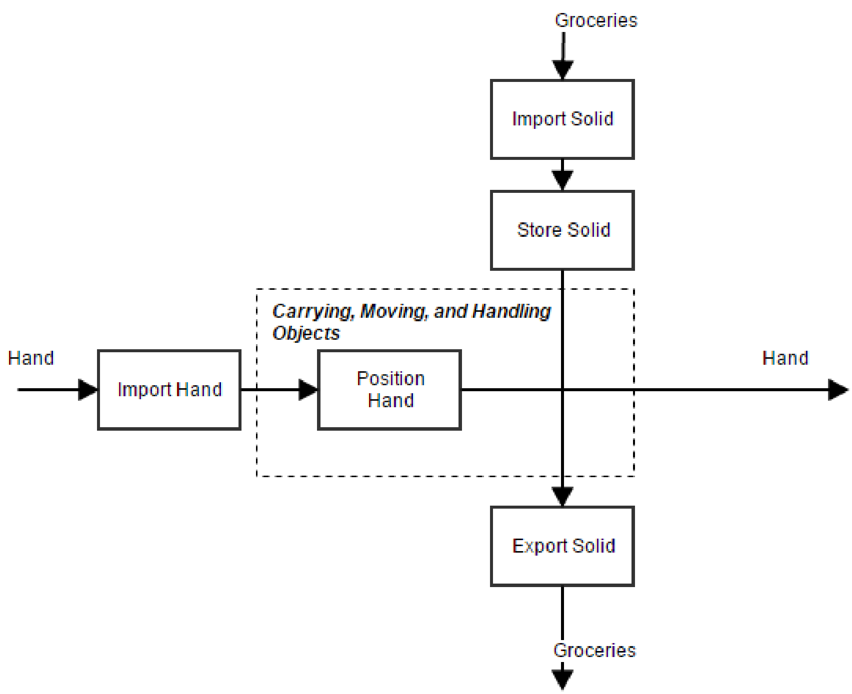
Users with physical impairments have difficulty exerting force with their arms extended. Consider the typical bow. While not typically associated with disabled users, archery is a sport many enjoy. Less able users would have difficulty drawing and steadying a typical bow, as they may not be strong enough to exert force with an outstretched arm.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bow as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Case 22: Grocery Bags

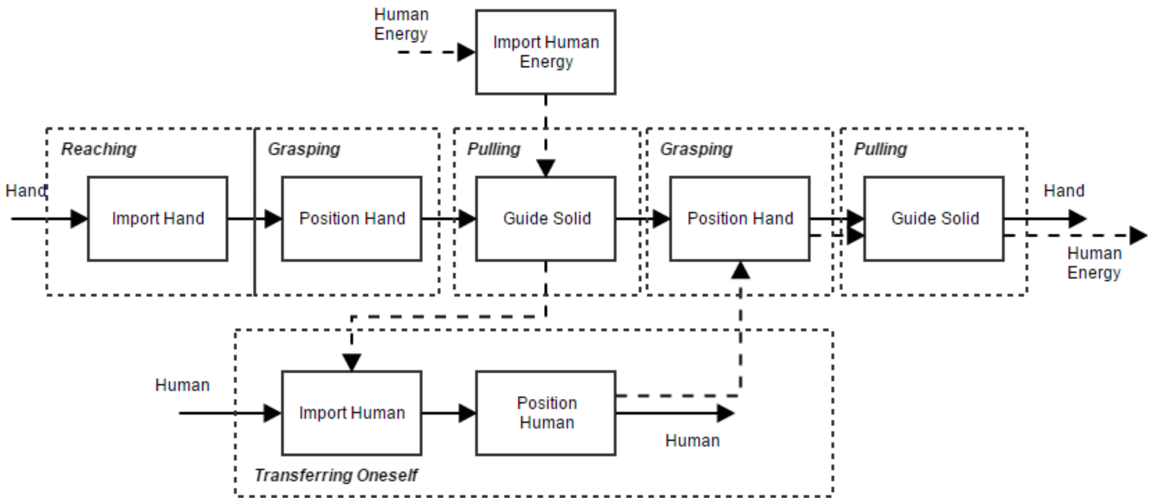
In order to make environments and products more accessible to all users, designers should consider changes to how a user positions their hands on the product to move or otherwise handle the object. Users with upper body disabilities will have difficulty grasping or carrying certain shapes of objects, so designers should consider changes in order to develop more inclusive products. A relevant product is a typical grocery bag. Users with hand impairments may not have the dexterity or strength required to properly carry the bag. Handling the grocery bag may be difficult for various reasons. The handles are narrow and do not provide much room for gripping, likewise the handles are not made of substantial material and may deform, tear, or cut into the user’s hand.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the grocery bags as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Case 32: Car Doors

Designers should consider users with diminished mobility when designing the access points for products and environments. Users with mobility impairments will have trouble transferring themselves into the car through the car door unassisted, as they may lack the coordination or strength necessary to pull themselves into the car. The figure below shows the actionfunction diagram for a typical car door.



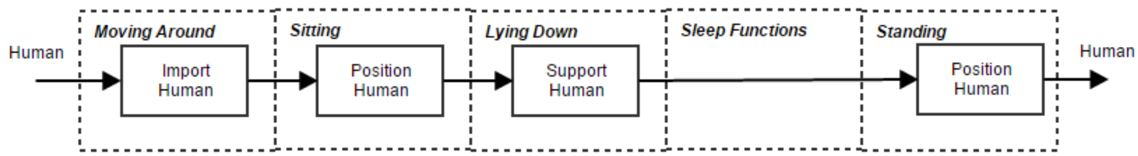
Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the car door as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Group

Three

Case 11: Bed

Users with lower body disabilities have difficulty standing and sitting unsupported. Designers should take this into consideration when designing products that requires users to sit on or stand up from. Consider the actionfunction diagram related to a user sitting on and standing up from a typical bed, provided below.

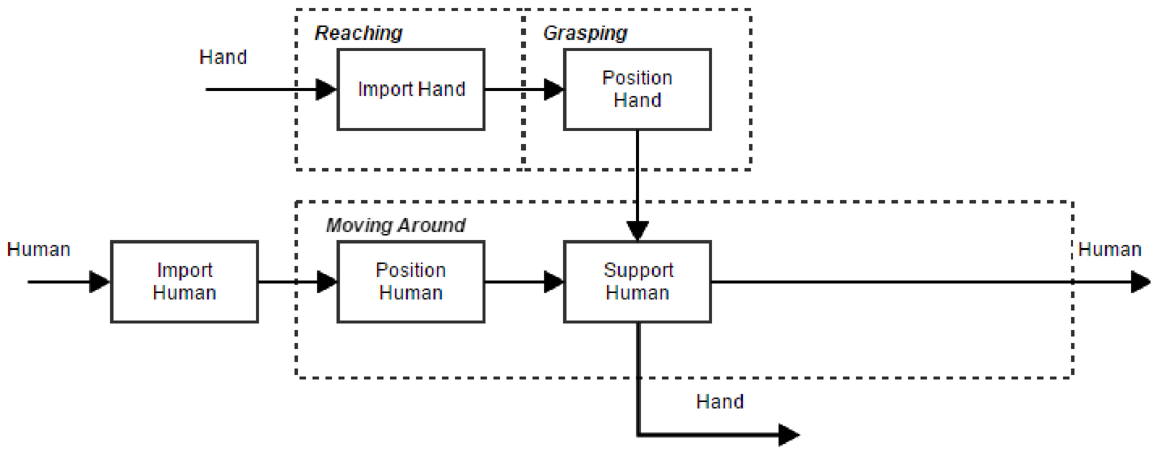


Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bed as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Case 12: Grab Bars

Grab bars and rails have the potential to be very obstructive and aesthetically displeasing. In order to avoid making products and environments look too ‘assistive’ or ‘medical’, designers should incorporate supports into the overall aesthetic of the design. By making products more aesthetically pleasing, designers can help remove some of the stigma of owning ‘assistive’ products, which could lead to more widespread use of the inclusive products.

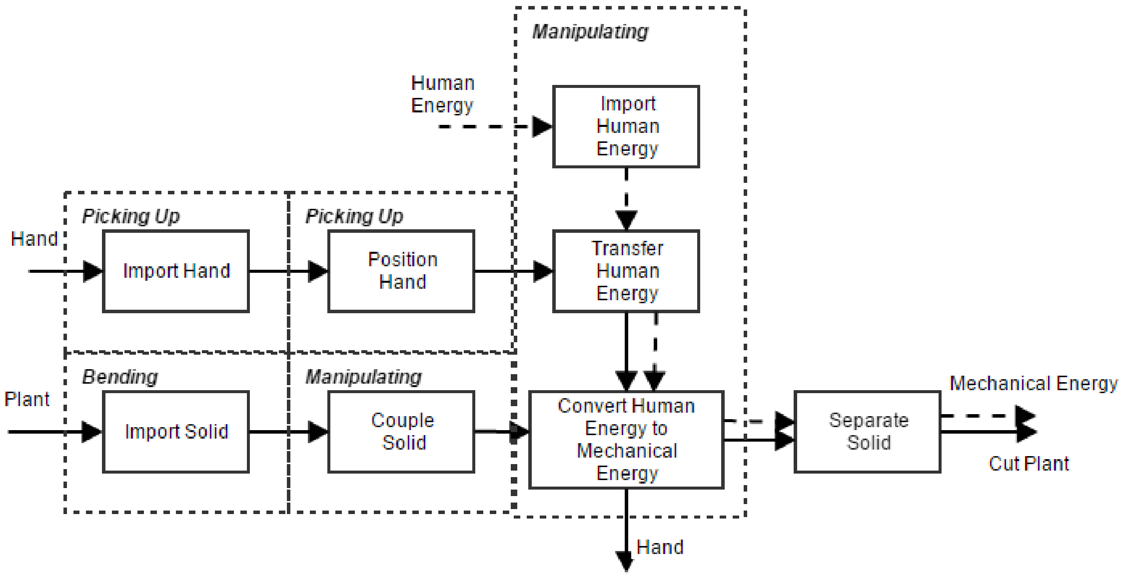
Consider the typical grab bars on a bath tub. Typical grab bars on bath tubs are seen as ‘assistive’ products, and could turn away some users. The actionfunction diagram for typical grab bars is given below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the grab bars as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Case 13: Garden Shears

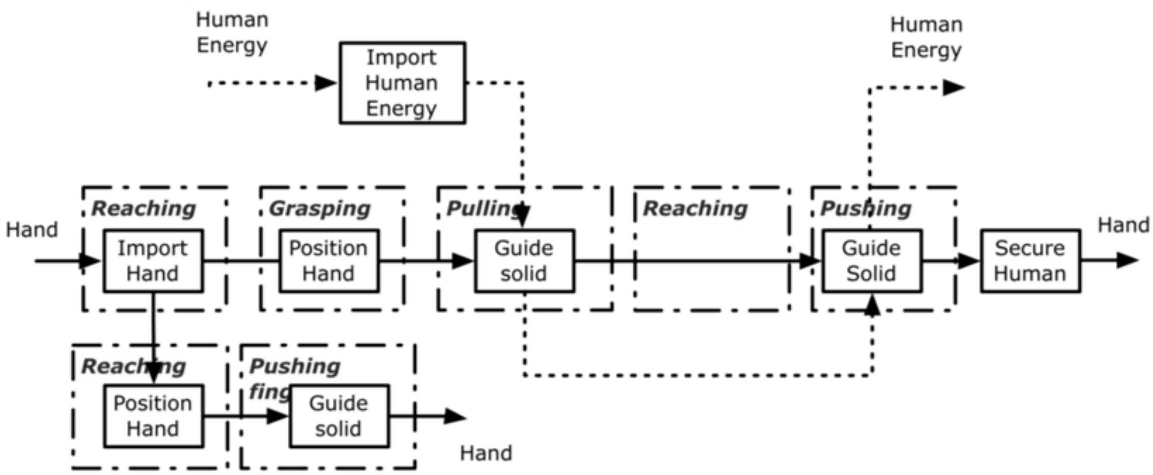
Users with limited lower body ability or back trouble have trouble bending at the waist. In order to develop more inclusive designs, designers should consider removing the need to bend over to utilize the product. Consider a typical set of garden shears, for which the corresponding actionfunction diagram has been provided.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the garden shears as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Case 25: Seat Belt

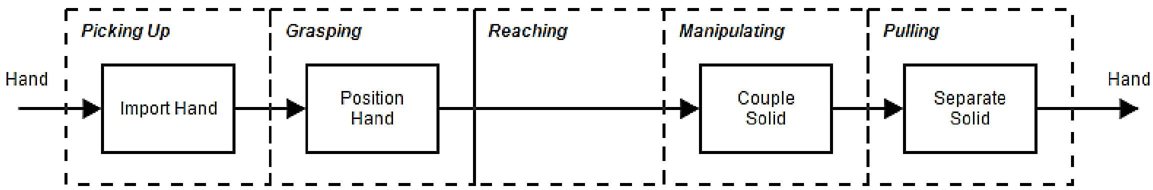
In order to make products more accessible to all users, designers should consider modifications relating to how a user would grip and guide parts of the product. Individuals with reduced grip strength may have difficulties manipulating small or unfamiliarly shaped objects. In this case, we consider the following actionfunction diagram of a typical seat belt.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the seat belt as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Case 26: Shaving Razor

In order to make products more accessible to all users, designers should consider changing certain parameters of the product relating to how a user brings the product in contact with other objects. In this case, we consider a typical shaving razor. Less able users might not be able to reach the razor far enough to contact their limbs. The relevant actionfunction diagram is pictured below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the razor as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Study Questionnaire

This questionnaire is meant to assess the usability of the methods you just practiced in the study assignment. The following questions will ask you to rate your opinion on various statements related to the method's usefulness. Here, method refers to the use of actionfunction diagrams to model user-product interaction and the use of inclusive design rules to aid in designing more accessible products.

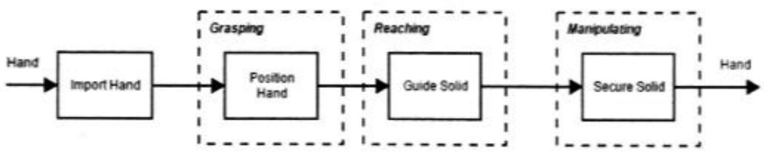
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I think that I would like to use actionfunction diagrams for inclusive design	○	○	○	○	○
I found actionfunction diagrams unnecessarily complex.	○	○	○	○	○
I thought the actionfunction diagram method was easy to use	○	○	○	○	○
I would imagine that most engineers could learn to use actionfunction diagrams quickly	○	○	○	○	○
I think that I would like to use these inclusive design rules in the design process.	○	○	○	○	○
I found the inclusive design rules unnecessarily complex.	○	○	○	○	○
I thought the inclusive design rules were easy to apply.	○	○	○	○	○
I was able to identify an applicable inclusive design rule in these problems.	○	○	○	○	○
I would imagine that most engineers could learn to use these inclusive design rules quickly.	○	○	○	○	○
I needed to learn a lot of things before I could get going with these methods.	○	○	○	○	○
With more practice I think I could become very proficient in using these methods.	○	○	○	○	○
Please provide any additional feedback here:					

APPENDIX H: VALIDATION STUDY RESPONSES

O2

Case 1: Fitted Bed Sheets

Users with diminished hand strength or dexterity, either due to age or injury, have trouble grasping products. Because they lack the necessary hand strength, users with impairments of the hand may not be able to maintain their grip on certain products as the user operates the product. In this case we consider the typical fitted bed sheet. In order to properly install the bed sheet, users must push and pull the sheet's edges around their mattress. Because fitted bed sheets contain elastic portions, it may be difficult for impaired users to pull the sheet after they have secured one or more corners. The actionfunction diagram for a typical bed sheet is shown below:



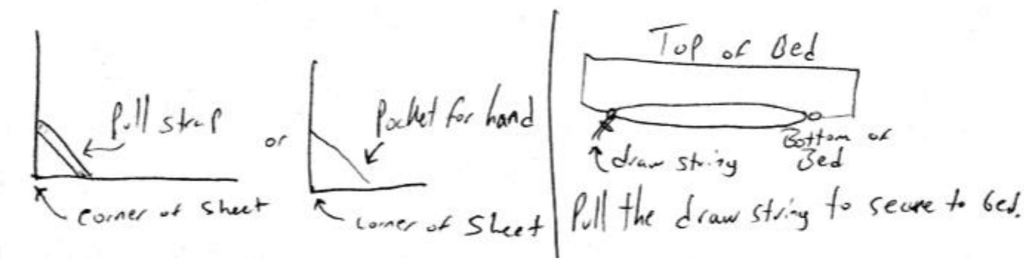
Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the fitted sheets as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

(Grasping, Position hand) $\xrightarrow{\text{morphological}}$ (Manipulating, Position hand)

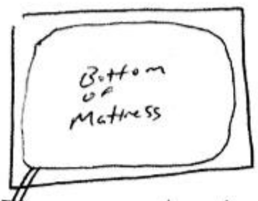
(Reaching, Guide Solid) $\xrightarrow{\text{parametric}}$ (Reaching, Guide Solid (easier))

(Manipulating, Secure Solid) $\xrightarrow{\text{functional}}$ (Manipulating, Secure Solid (easier))

The bed sheet could be made without elastic, using a draw-string instead. The corners could also have handles or pockets that a hand can be placed in to remove the need for manual dexterity with individual fingers. Removing the elastic band will decrease the force required to position and secure the sheet.



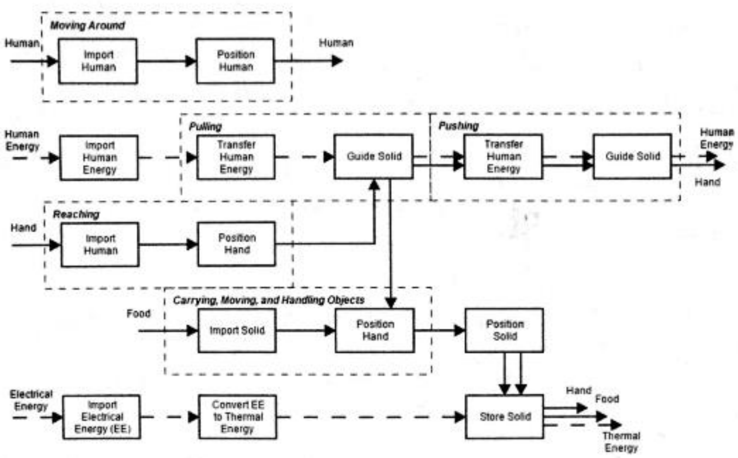
Case 1: Fitted Bed Sheets (continued)



Pulling the draw string will tighten the sheet and secure it to the bed.

Case 2: Refrigerator Door Latch

Consider the typical refrigerator. Users with diminished strength may find the force requirements too high for breaking the seal and opening the refrigerator door. Refrigerator door seals are generally tight due to magnetic strips as well as the pressure differential between the cool air inside and the warm air outside. While users may still be able to open the door through considerable application of their force, it could be beneficial for designers to develop a more easy to open refrigerator for persons suffering from arthritis, injuries, or other debilitating conditions. The actionfunction diagram for a refrigerator is provided below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the refrigerator as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Pushing is usually easier than pulling for people with dexterity issues because pulling requires grasping of some sort. There could also be a change to the design to incorporate something easier to pull on when necessary.

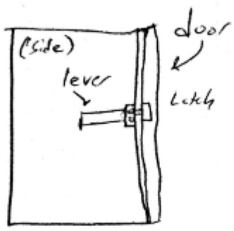
(Guide Solid, Pulling) → (Guide Solid, Pushing)
Morphological, Change activity

Case 2: Refrigerator Door Latch (continued)

(Reaching, Position hand) $\xrightarrow[\text{Morphological}]{}$ (Reaching, Position hand (easier))

Change #1, 2.1)

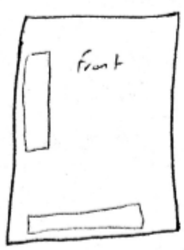
Incorporate a push-actuated opener on the fridge. Many industrial refrigerators have pull-to-open latches that could be re-designed to be push-to-open. A simple lever-operated mechanism that could break the initial seal of the refrigerator would help with opening. A person could lean on it, push it with an arm/leg/shoulder, etc.



designed so the push on the lever would pull open the door. Something better than my sketch.

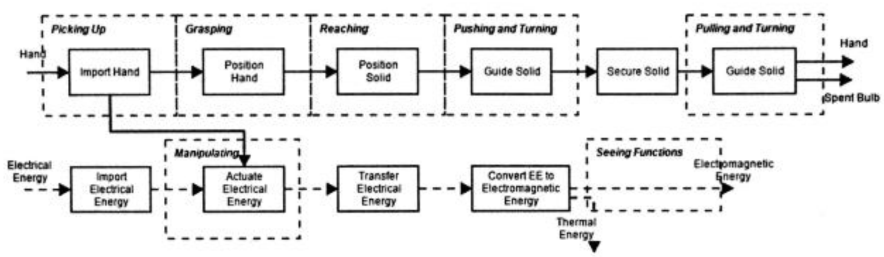
Change #2 2.2)

Put a larger, easier to grasp or pull handle on the refrigerator. Possibly include a foot-pull on the door.



Case 3: Light Bulb

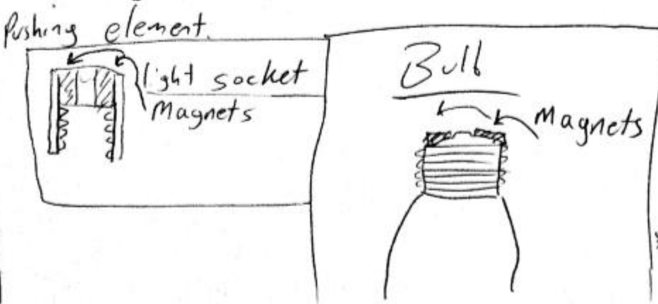
Users with diminished hand strength may have difficulties performing activities that require simultaneous manipulations. A classic example of a product that requires simultaneous manipulations is the child-proof pill bottle cap, which requires users to push and twist at the same time to disengage the cap. Many users have difficulty opening a pill bottle, which has led to many inclusive design alternatives, such as arthritis-friendly bottle caps. A lesser considered product that requires simultaneous manipulations is a lightbulb, as users must push and turn the lightbulb in order to install it. The actionfunction diagram for a light bulb is provided below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the light bulb as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

(Pushing and Turning, Guide Solid) $\xrightarrow[\text{Morphological}]{}$ (Pushing and turning (easier))

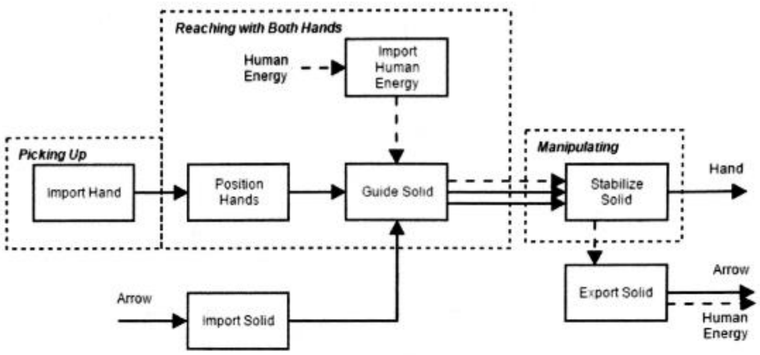
Some sort of device to hold the light bulb in place while turning it could be used. While it would require a redesign of the socket, magnets could be used. One element of the Pushing and turning needs to be removed, and magnets would remove the Pushing element.



The bulb would be held in place while securing it with the magnets.
*Maybe the threads wouldn't be necessary?

Case 6: Bow

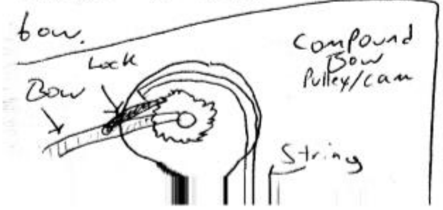
In order to make products more inclusive, designers should allow for users to operate products with a single hand, rather than two. Consider the following actionfunction diagram of a typical bow. In using a typical bow, users must exert force with both arms to draw and steady the bow. Apply the corresponding design rule and develop a physical representation of the resulting product. The typical bow actionfunction diagram is provided below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bow as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

(Transfer human energy, Pulling Solids) $\xrightarrow[\text{Morphological}]{}$ (Trasfer human energy, Pulling Solids (easier))

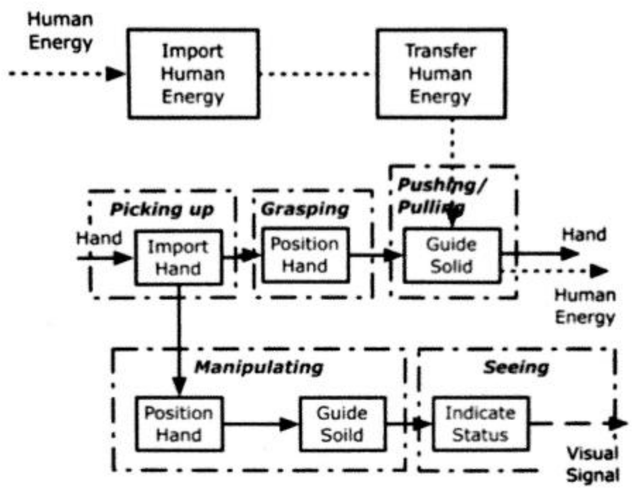
A locking mechanism could be used to allow the person to draw the bow in a more comfortable/easier position, and lock the string in place until they are ready to release. Locking gears could be used on a compound bow to hold the energy until release. This would decrease the force required while steadying the bow.



The lock could be actuated on the Bow itself somewhere.

Case 28: Clothes Iron

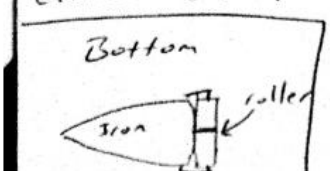
Designers should consider users with upper body disabilities, or otherwise reduced upper body strength, when developing products that require the user to pull and guide some portion of the product. By enacting some change, designers can alter the product so that the moving parts are no longer associated with a user activity, and are instead accomplished by the product itself. Consider a typical iron, for which the actionfunction diagram is provided below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the clothes iron as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

(Guide Solid, Pushing/Pulling) → (Guide Solid, Pushing/Pulling (easier))
morphological

a set of rollers could be used on the iron to make moving it over clothes easier.

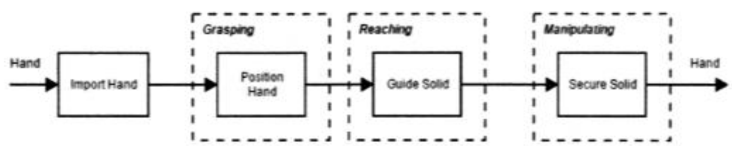


Instead of completely picking up the weight of the iron, it could be tilted to allow for ease of movement over the clothes

08

Case 1: Fitted Bed Sheets

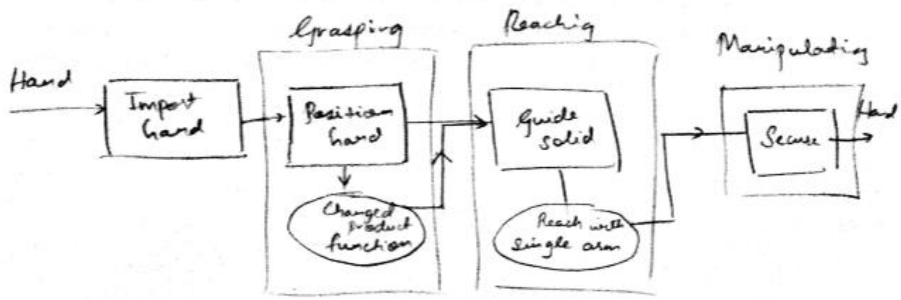
Users with diminished hand strength or dexterity, either due to age or injury, have trouble grasping products. Because they lack the necessary hand strength, users with impairments of the hand may not be able to maintain their grip on certain products as the user operates the product. In this case we consider the typical fitted bed sheet. In order to properly install the bed sheet, users must push and pull the sheet's edges around their mattress. Because fitted bed sheets contain elastic portions, it may be difficult for impaired users to pull the sheet after they have secured one or more corners. The actionfunction diagram for a typical bed sheet is shown below:



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the fitted sheets as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

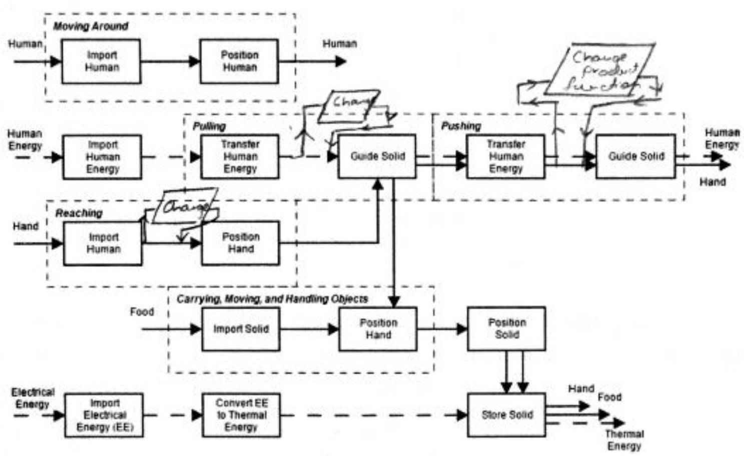
→ Since grasping the sheet may be difficult for impaired users, a morphological product change can be included.

→ Also, reach & stretch for a single arm can be utilized for better functionality.



Case 2: Refrigerator Door Latch

Consider the typical refrigerator. Users with diminished strength may find the force requirements too high for breaking the seal and opening the refrigerator door. Refrigerator door seals are generally tight due to magnetic strips as well as the pressure differential between the cool air inside and the warm air outside. While users may still be able to open the door through considerable application of their force, it could be beneficial for designers to develop a more easy to open refrigerator for persons suffering from arthritis, injuries, or other debilitating conditions. The actionfunction diagram for a refrigerator is provided below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the refrigerator as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

→ Human energy → Pulling

↳ Parametric change can be applied to make activity easier

Case 2: Refrigerator Door Latch (continued)

→ Pushing with hand

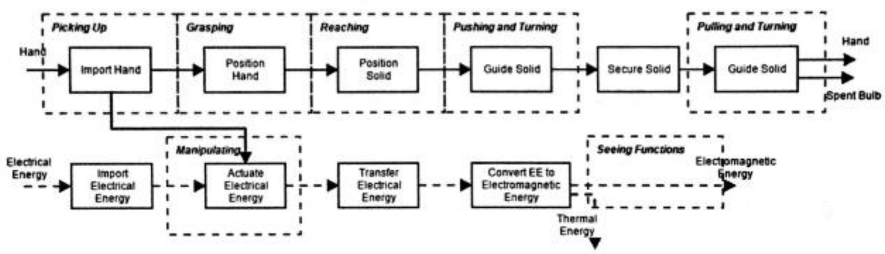
↳ Parametric change can be applied

→ Reaching

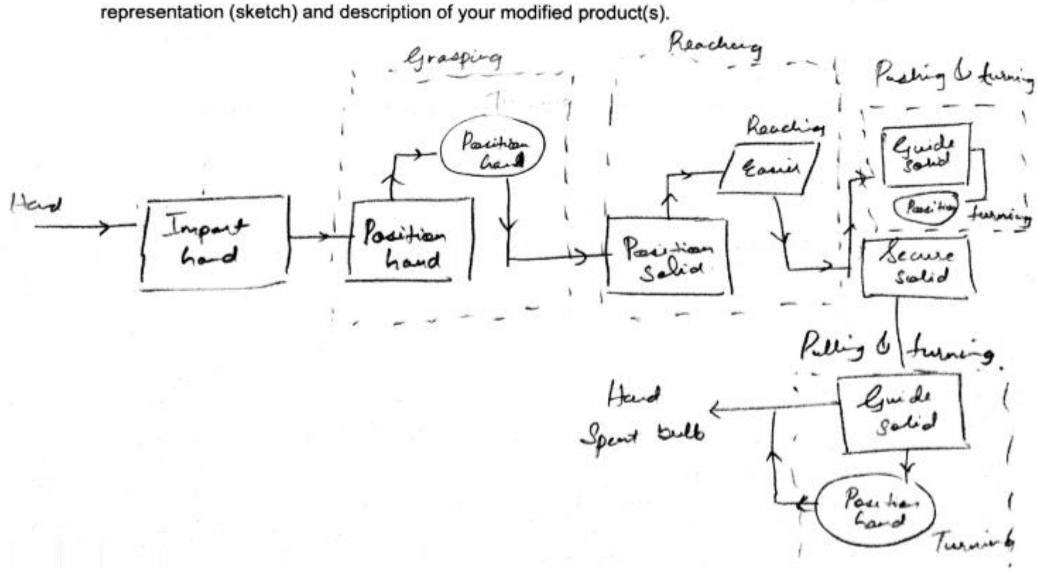
↳ Parametric change can be applied for easier operation

Case 3: Light Bulb

Users with diminished hand strength may have difficulties performing activities that require simultaneous manipulations. A classic example of a product that requires simultaneous manipulations is the child-proof pill bottle cap, which requires users to push and twist at the same time to disengage the cap. Many users have difficulty opening a pill bottle, which has led to many inclusive design alternatives, such as arthritis-friendly bottle caps. A lesser considered product that requires simultaneous manipulations is a lightbulb, as users must push and turn the lightbulb in order to install it. The actionfunction diagram for a light bulb is provided below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the light bulb as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).



Case 3: Light Bulb (continued)

Grasping → Morphological → position had

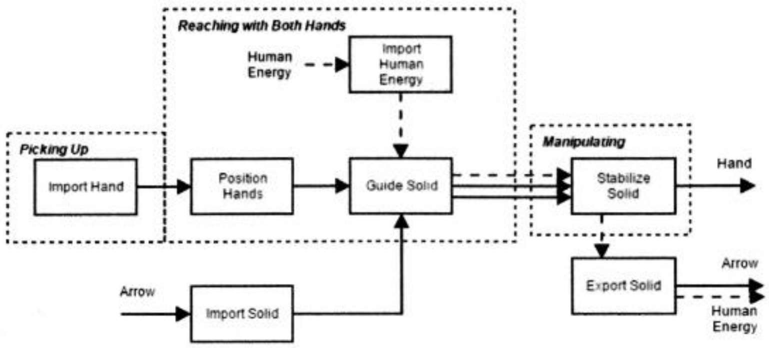
Reaching → Parametric → position hand

Pushing & turning → morphological ⟶

Pulling & turning → morphological ⟶ Guide solid.

Case 6: Bow

In order to make products more inclusive, designers should allow for users to operate products with a single hand, rather than two. Consider the following actionfunction diagram of a typical bow. In using a typical bow, users must exert force with both arms to draw and steady the bow. Apply the corresponding design rule and develop a physical representation of the resulting product. The typical bow actionfunction diagram is provided below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bow as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

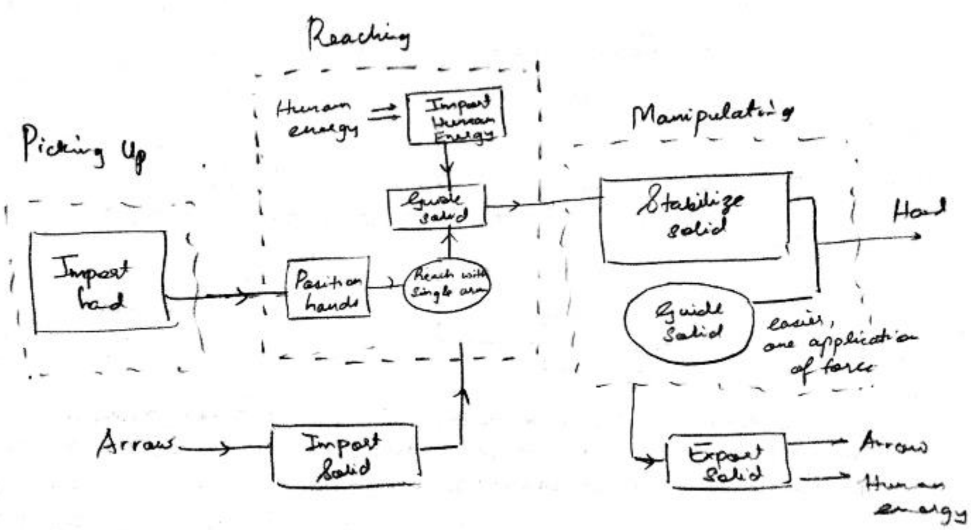
↳ Reaching → position hand → morphological

Reach with single arm

↳ Manipulating → Guide solid → morphological

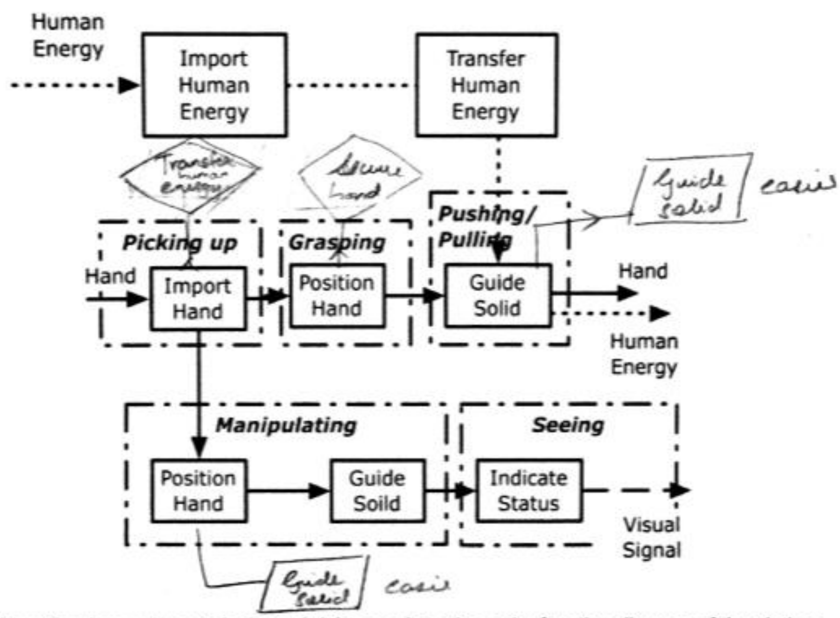
Easier, one application of force

Case 6: Bow (continued)



Case 28: Clothes Iron

Designers should consider users with upper body disabilities, or otherwise reduced upper body strength, when developing products that require the user to pull and guide some portion of the product. By enacting some change, designers can alter the product so that the moving parts are no longer associated with a user activity, and are instead accomplished by the product itself. Consider a typical iron, for which the actionfunction diagram is provided below.

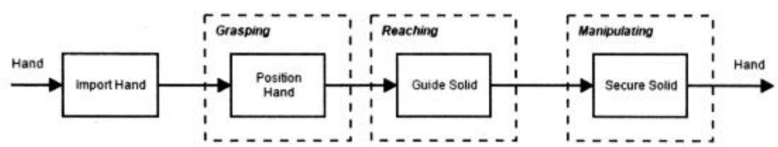


Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the clothes iron as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

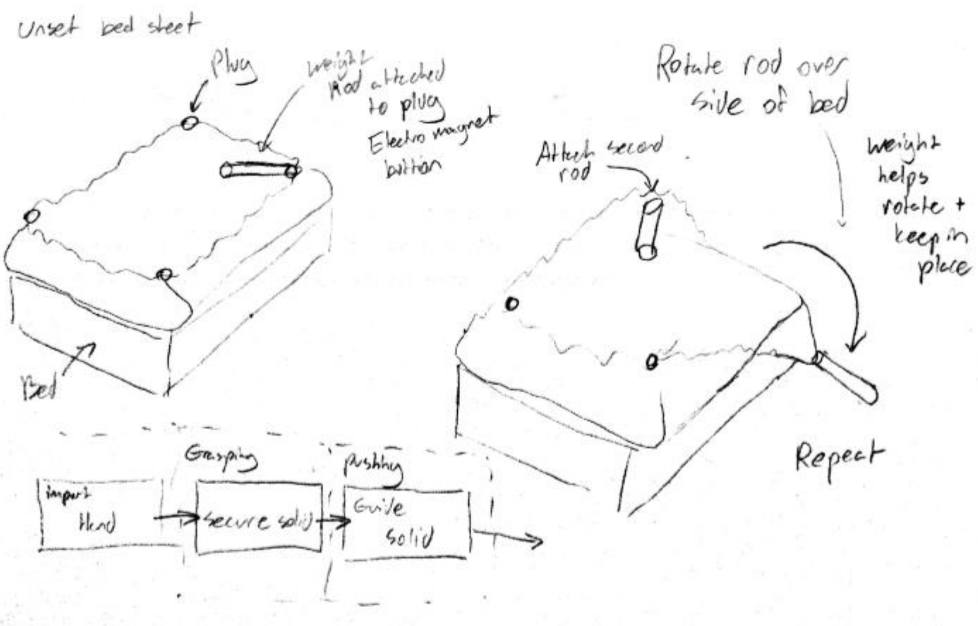
09

Case 1: ***Fitted Bed Sheets***

Users with diminished hand strength or dexterity, either due to age or injury, have trouble grasping products. Because they lack the necessary hand strength, users with impairments of the hand may not be able to maintain their grip on certain products as the user operates the product. In this case we consider the typical fitted bed sheet. In order to properly install the bed sheet, users must push and pull the sheet's edges around their mattress. Because fitted bed sheets contain elastic portions, it may be difficult for impaired users to pull the sheet after they have secured one or more corners. The actionfunction diagram for a typical bed sheet is shown below:

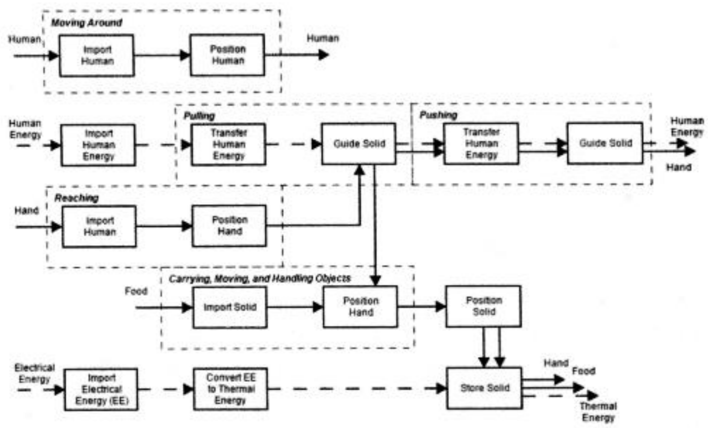


Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the fitted sheets as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).



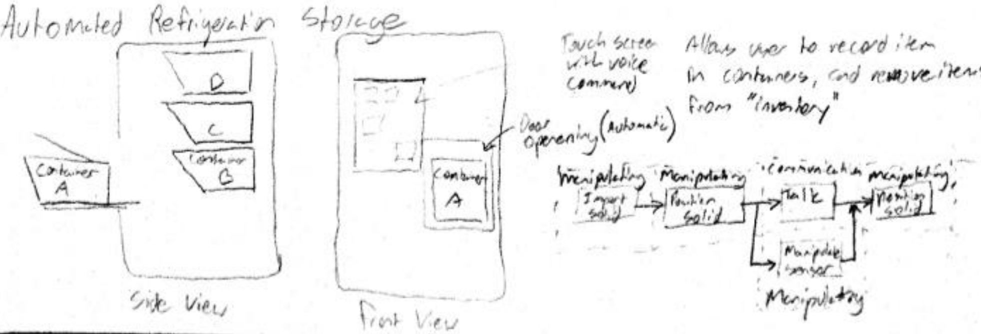
Case 2: Refrigerator Door Latch

Consider the typical refrigerator. Users with diminished strength may find the force requirements too high for breaking the seal and opening the refrigerator door. Refrigerator door seals are generally tight due to magnetic strips as well as the pressure differential between the cool air inside and the warm air outside. While users may still be able to open the door through considerable application of their force, it could be beneficial for designers to develop a more easy to open refrigerator for persons suffering from arthritis, injuries, or other debilitating conditions. The actionfunction diagram for a refrigerator is provided below.



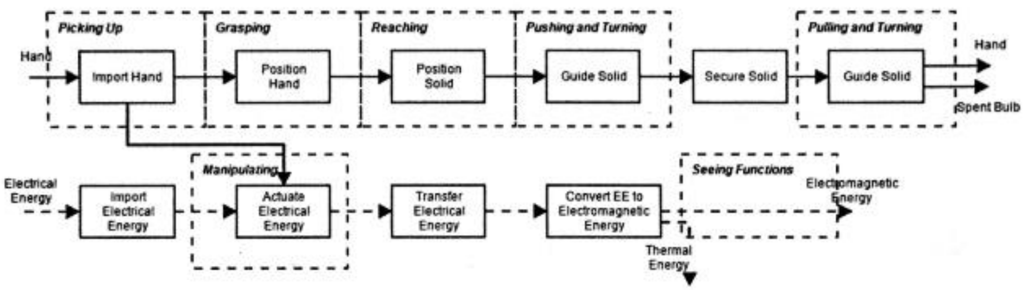
Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the refrigerator as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Automated Refrigeration Storage



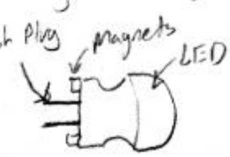
Case 3: Light Bulb

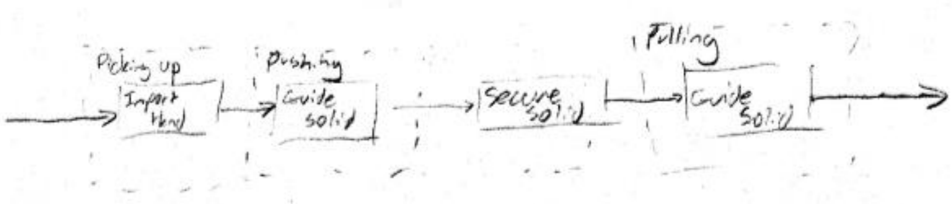
Users with diminished hand strength may have difficulties performing activities that require simultaneous manipulations. A classic example of a product that requires simultaneous manipulations is the child-proof pill bottle cap, which requires users to push and twist at the same time to disengage the cap. Many users have difficulty opening a pill bottle, which has led to many inclusive design alternatives, such as arthritis-friendly bottle caps. A lesser considered product that requires simultaneous manipulations is a lightbulb, as users must push and turn the lightbulb in order to install it. The actionfunction diagram for a light bulb is provided below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the light bulb as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

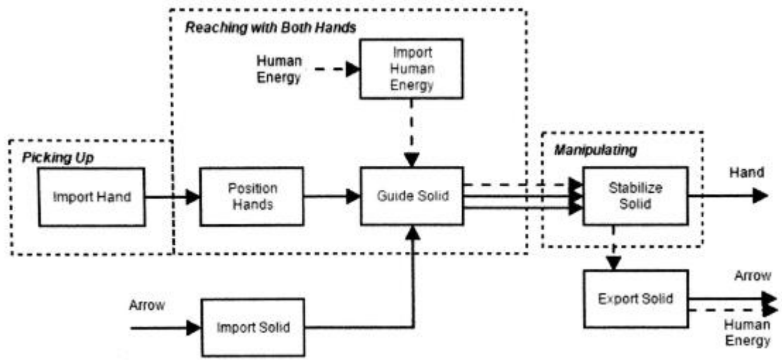
Large LED Bank with push plug and magnets





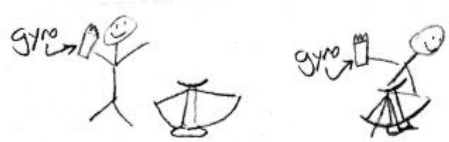
Case 6: Bow

In order to make products more inclusive, designers should allow for users to operate products with a single hand, rather than two. Consider the following actionfunction diagram of a typical bow. In using a typical bow, users must exert force with both arms to draw and steady the bow. Apply the corresponding design rule and develop a physical representation of the resulting product. The typical bow actionfunction diagram is provided below.

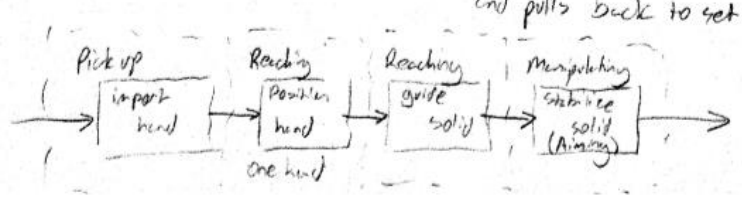


Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bow as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Gastrophetes

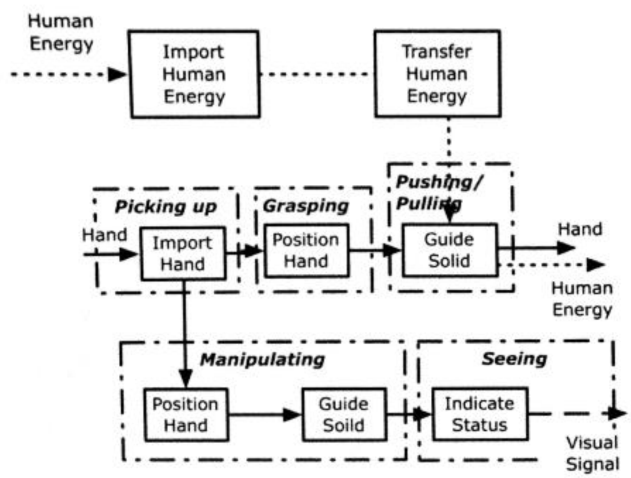


- Person steps on front loop of bow foot stabilizes bow because loop is flat in one section
- person presses bow against stomach and leans in slightly to "Lock" bow in place
- person grabs string with one or both arms and pulls back to set bow



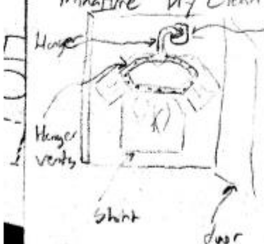
Case 28: *Clothes Iron*

Designers should consider users with upper body disabilities, or otherwise reduced upper body strength, when developing products that require the user to pull and guide some portion of the product. By enacting some change, designers can alter the product so that the moving parts are no longer associated with a user activity, and are instead accomplished by the product itself. Consider a typical iron, for which the actionfunction diagram is provided below.

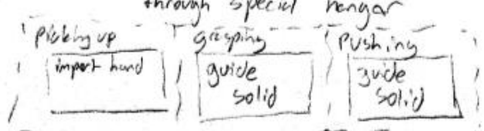


Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the clothes iron as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Minature Dry Clean hanger

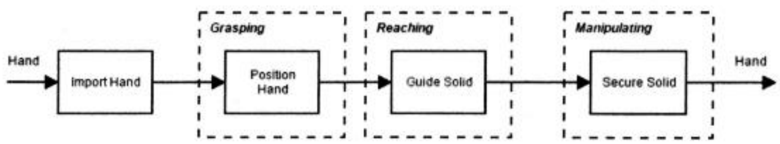


- Hook hanger into port with shirt on
- Close door
- Steam clean system blows out wrinkles through special hangar

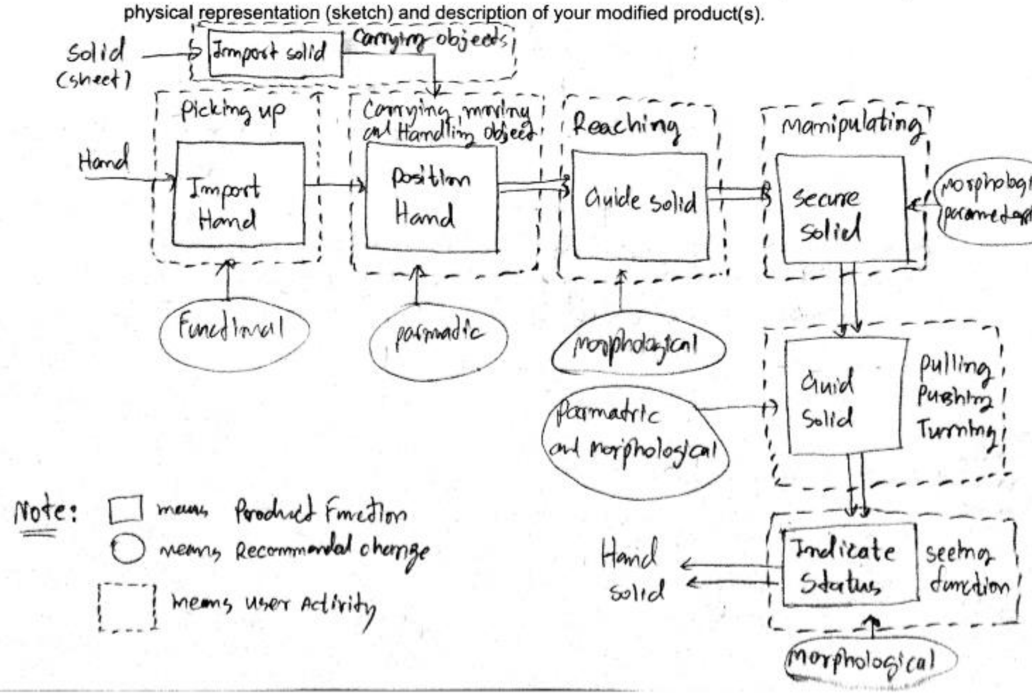


Case 1: Fitted Bed Sheets

Users with diminished hand strength or dexterity, either due to age or injury, have trouble grasping products. Because they lack the necessary hand strength, users with impairments of the hand may not be able to maintain their grip on certain products as the user operates the product. In this case we consider the typical fitted bed sheet. In order to properly install the bed sheet, users must push and pull the sheet's edges around their mattress. Because fitted bed sheets contain elastic portions, it may be difficult for impaired users to pull the sheet after they have secured one or more corners. The actionfunction diagram for a typical bed sheet is shown below:

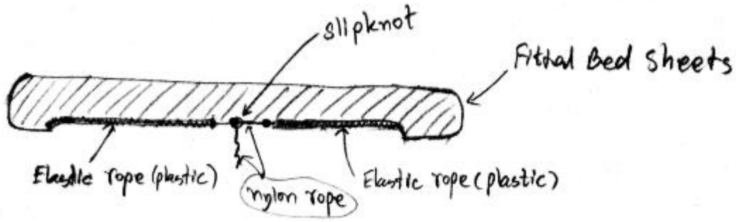


Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the fitted sheets as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

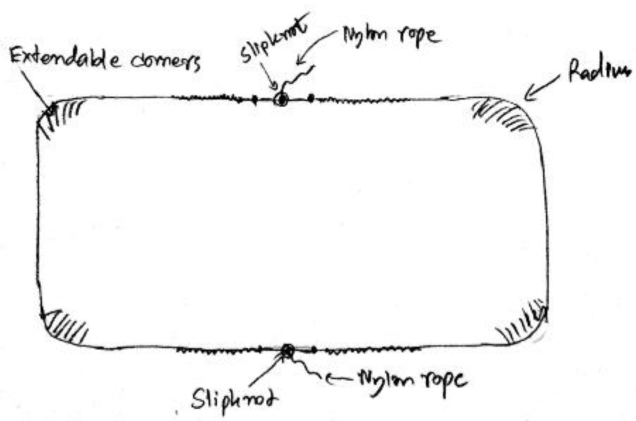


Case 1: Fitted Bed Sheets (continued)

A physical representation (sketch)

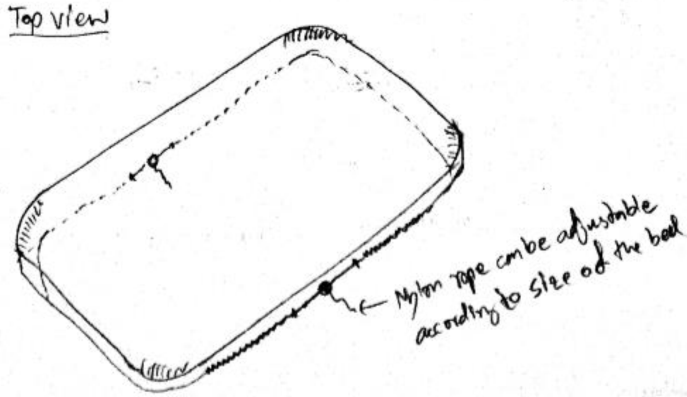


Front view



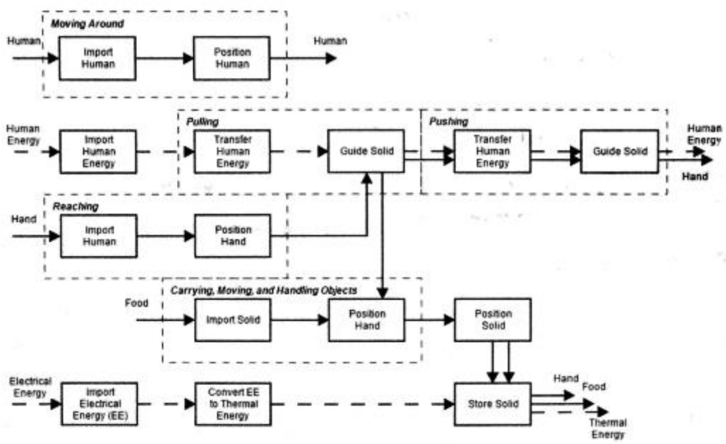
Top view

There are 2 pieces of slipknot on both sides.



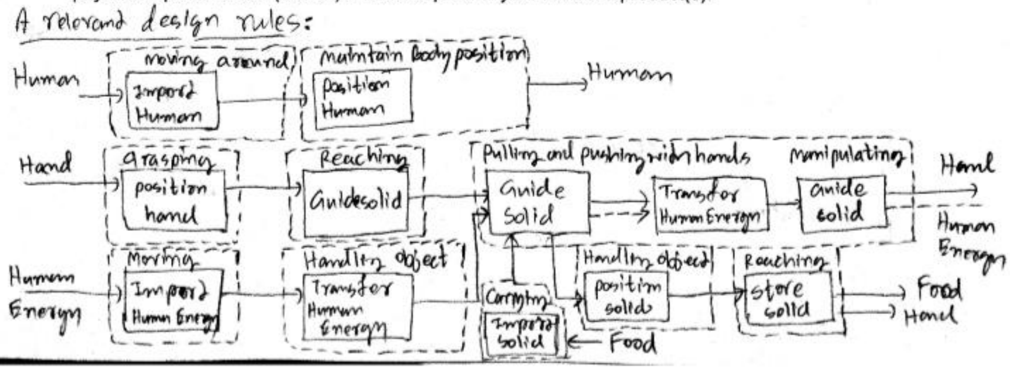
Case 2: Refrigerator Door Latch

Consider the typical refrigerator. Users with diminished strength may find the force requirements too high for breaking the seal and opening the refrigerator door. Refrigerator door seals are generally tight due to magnetic strips as well as the pressure differential between the cool air inside and the warm air outside. While users may still be able to open the door through considerable application of their force, it could be beneficial for designers to develop a more easy to open refrigerator for persons suffering from arthritis, injuries, or other debilitating conditions. The actionfunction diagram for a refrigerator is provided below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the refrigerator as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

A relevant design rules:



Case 2: *Refrigerator Door Latch* (continued)

Note: [ ] means Product Functions
[ ] means Human Activity.

Recommended changes: (1) Human: Import Human → No change
position Hand → Maintain Body Position

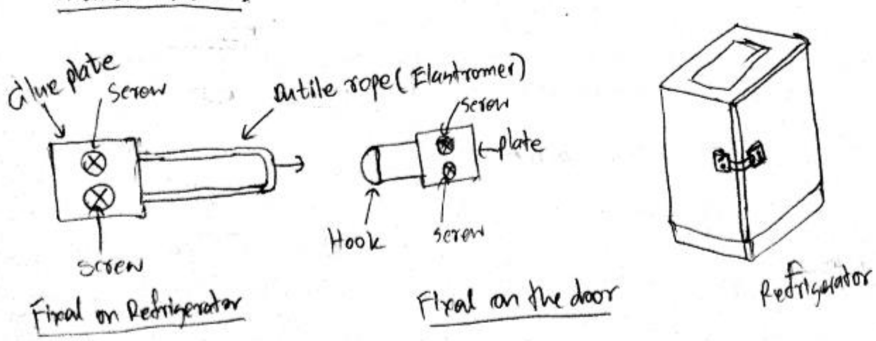
(2) Hand: position Hand → parametric
Guide solid → morphological
Guide solid → Parametric
Transfer Human Energy → Morphological
Guid solid → Morphological

(3) Human Energy: Import Human Energy → no change
Transfer Human Energy → Functional

(4) Food: Import solid → No change
Guide solid → morphological
Position solid → parametric
store solid → morphological

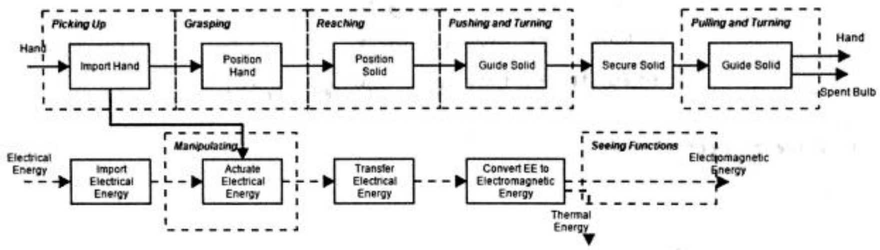
(5) No Electrical and Magnetic Energy

Product Sketch:

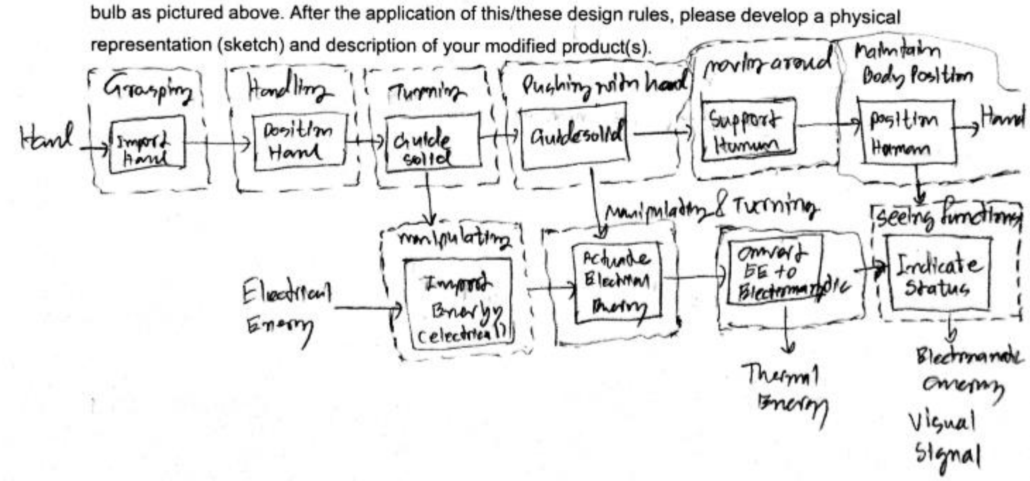


Case 3: Light Bulb

Users with diminished hand strength may have difficulties performing activities that require simultaneous manipulations. A classic example of a product that requires simultaneous manipulations is the child-proof pill bottle cap, which requires users to push and twist at the same time to disengage the cap. Many users have difficulty opening a pill bottle, which has led to many inclusive design alternatives, such as arthritis-friendly bottle caps. A lesser considered product that requires simultaneous manipulations is a lightbulb, as users must push and turn the lightbulb in order to install it. The actionfunction diagram for a light bulb is provided below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the light bulb as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).



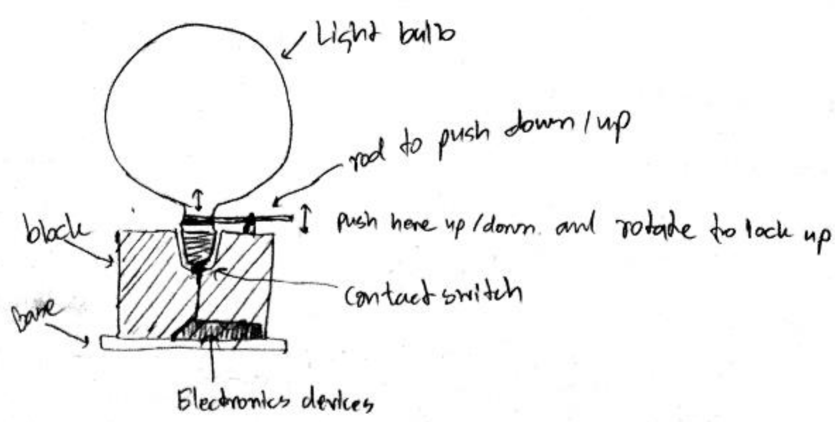
Case 3: Light Bulb (continued)

Recommendal changes

① Hand : Import Hand → No change
position Hand → Morphological
Guid solid → morphological and parametric
Guid solid → morphological
position Human → parametric

② EE Energy : Import EE Energy → Functional
Actuate EE Energy → parametric
Indicate statute → parametric

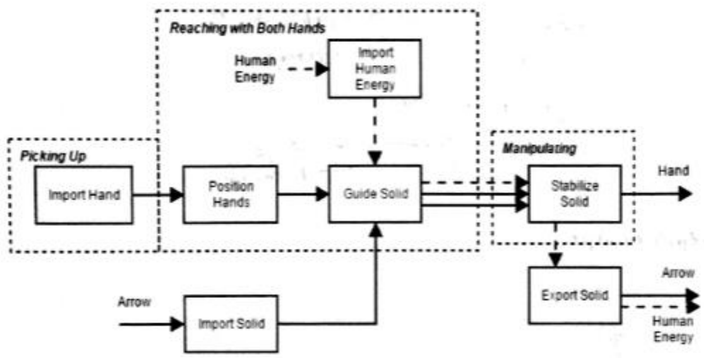
Product sketch



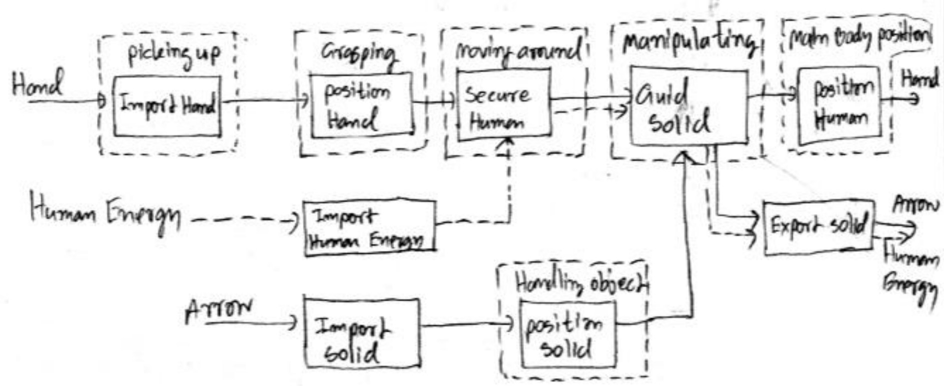
Section cut view

Case 6: Bow

In order to make products more inclusive, designers should allow for users to operate products with a single hand, rather than two. Consider the following actionfunction diagram of a typical bow. In using a typical bow, users must exert force with both arms to draw and steady the bow. Apply the corresponding design rule and develop a physical representation of the resulting product. The typical bow actionfunction diagram is provided below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bow as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).



Case 6: Bow (continued)

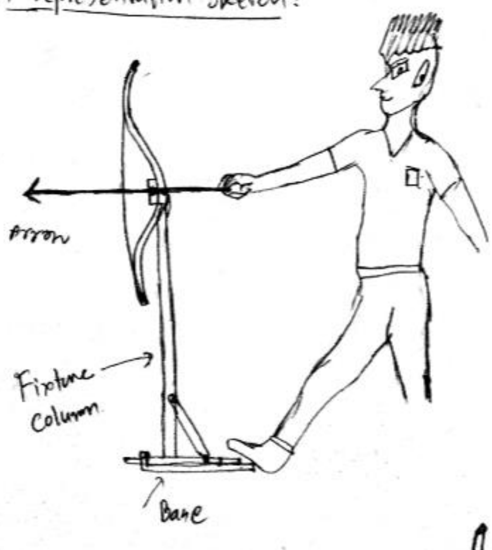
Recommended changes:

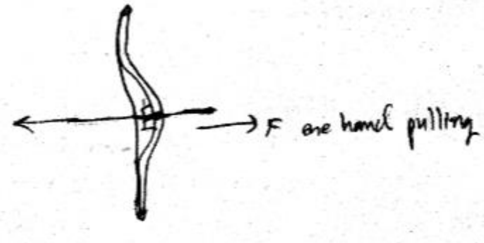
① Hand : Import hand → no change
position hand → parametric and morphological
Secure Human → Functional
Guid solid → morphological
position Human → parametric

② Human Energy : no change

③ Arrow : Import solid → no change
position solid → morphological

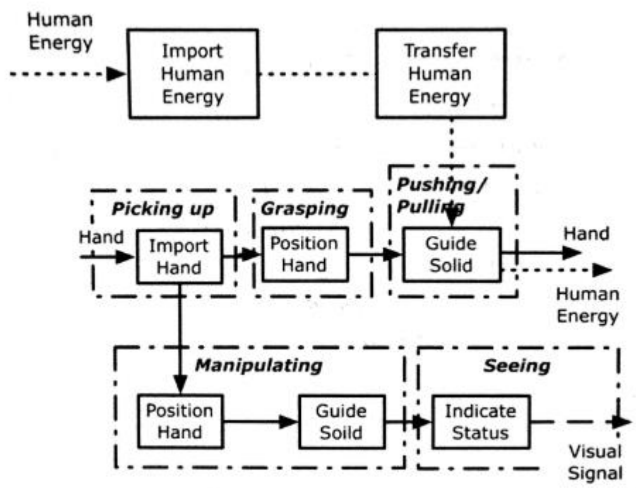
A representation sketch:



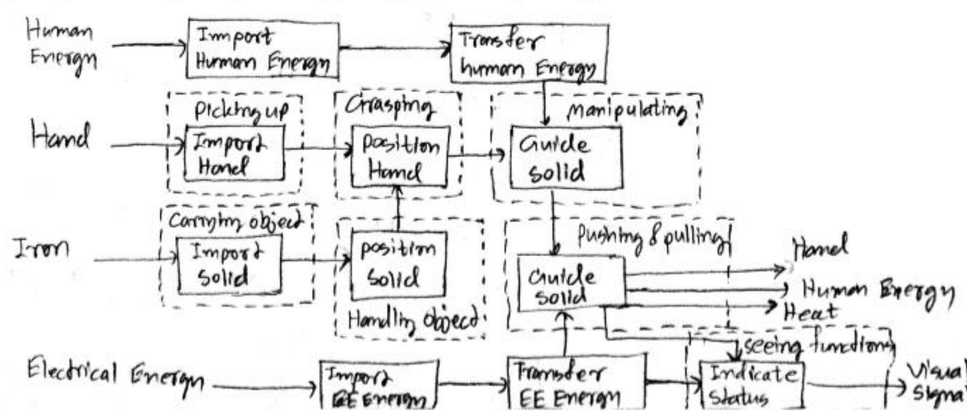


Case 28: Clothes Iron

Designers should consider users with upper body disabilities, or otherwise reduced upper body strength, when developing products that require the user to pull and guide some portion of the product. By enacting some change, designers can alter the product so that the moving parts are no longer associated with a user activity, and are instead accomplished by the product itself. Consider a typical iron, for which the actionfunction diagram is provided below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the clothes iron as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).



Case 28: Clothes Iron (continued)

Recommend changes:

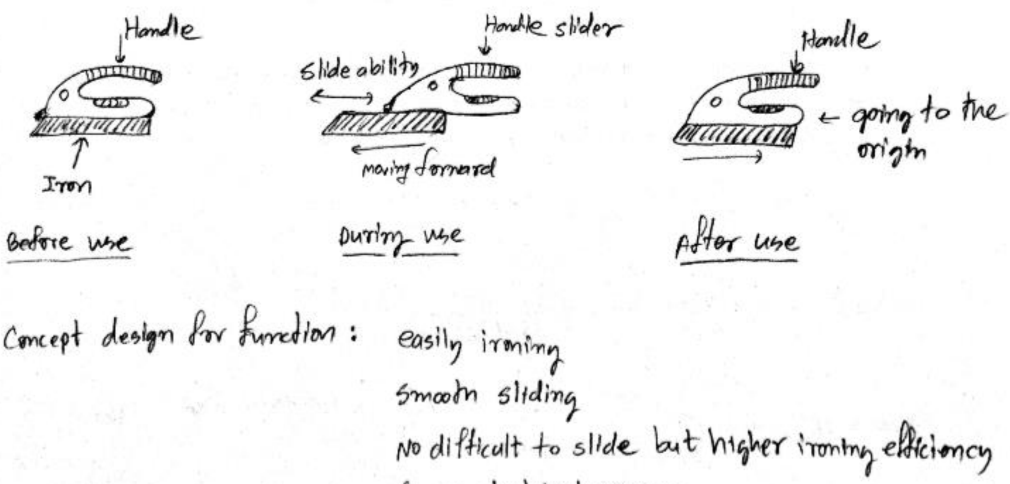
(1) Human Energy: Import Human Energy → No change
Transfer Human Energy → No change

(2) Hand: Import Hand → No change
position hand → parametric and morphological
Guide solid → parametric and morphological
Guide solid → parametric and morphological

(3) Iron: Import solid → No change
position solid → Morphological

(4) Electrical Energy: Import EE Energy → No change
Transfer EE Energy to Heat → parametric
Indicate status → parametric

A Product sketch (Iron)



Before use

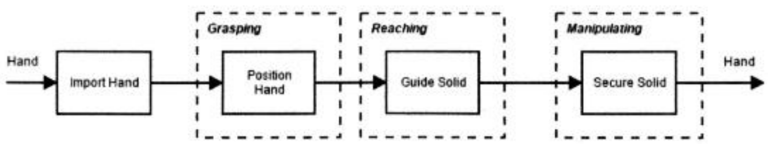
During use

After use

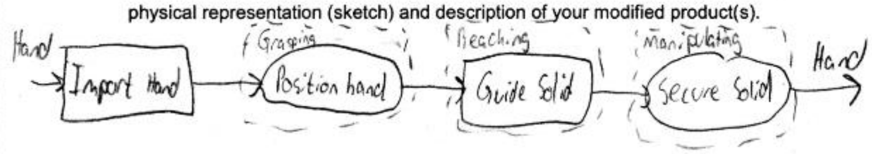
Concept design for function: easily ironing
Smooth sliding
No difficult to slide but higher ironing efficiency
Save electrical energy

Case 1: Fitted Bed Sheets

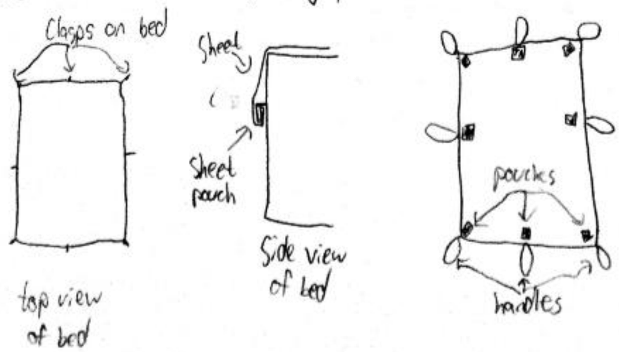
Users with diminished hand strength or dexterity, either due to age or injury, have trouble grasping products. Because they lack the necessary hand strength, users with impairments of the hand may not be able to maintain their grip on certain products as the user operates the product. In this case we consider the typical fitted bed sheet. In order to properly install the bed sheet, users must push and pull the sheet's edges around their mattress. Because fitted bed sheets contain elastic portions, it may be difficult for impaired users to pull the sheet after they have secured one or more corners. The actionfunction diagram for a typical bed sheet is shown below:



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the fitted sheets as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

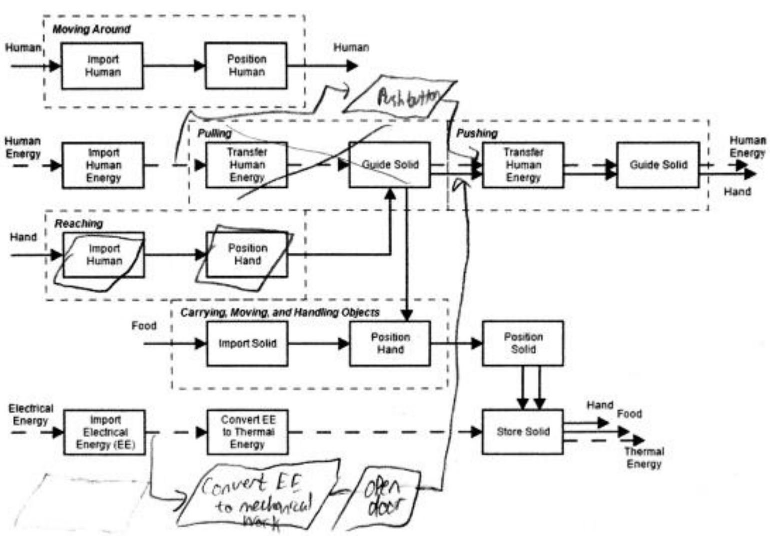


add handles to the sheet at locations by where it attaches to the mattress. Clasps are added to the mattress with corresponding pouches sewed into the sheets to secure it.



Case 2: Refrigerator Door Latch

Consider the typical refrigerator. Users with diminished strength may find the force requirements too high for breaking the seal and opening the refrigerator door. Refrigerator door seals are generally tight due to magnetic strips as well as the pressure differential between the cool air inside and the warm air outside. While users may still be able to open the door through considerable application of their force, it could be beneficial for designers to develop a more easy to open refrigerator for persons suffering from arthritis, injuries, or other debilitating conditions. The actionfunction diagram for a refrigerator is provided below.

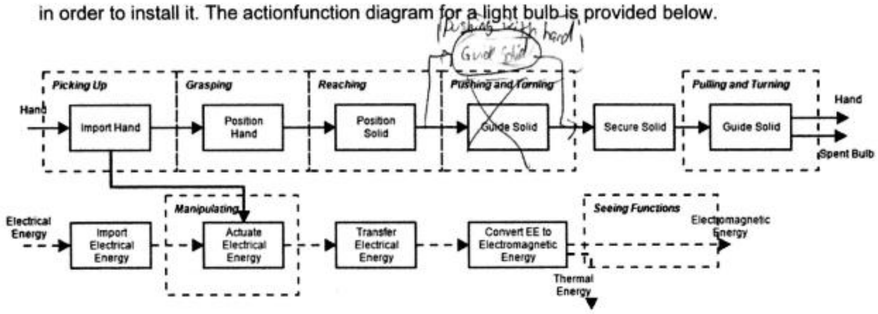


Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the refrigerator as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Install a motorized solution that will break the seal of the refrigerator with the touch of a button. Once it is cracked it is easy for the user to open and close the door.

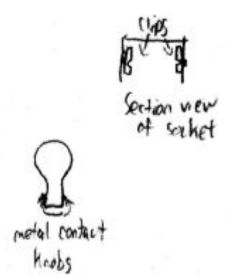
Case 3: Light Bulb

Users with diminished hand strength may have difficulties performing activities that require simultaneous manipulations. A classic example of a product that requires simultaneous manipulations is the child-proof pill bottle cap, which requires users to push and twist at the same time to disengage the cap. Many users have difficulty opening a pill bottle, which has led to many inclusive design alternatives, such as arthritis-friendly bottle caps. A lesser considered product that requires simultaneous manipulations is a lightbulb, as users must push and turn the lightbulb in order to install it. The actionfunction diagram for a light bulb is provided below.



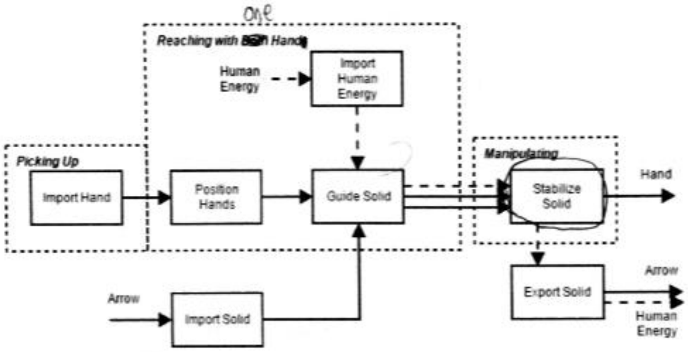
Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the light bulb as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Create special lightbulbs + socket so that the contacts creating the circuit couple through a spring loaded clip. The lightbulbs would only need to be pushed into the socket for installation. Have a mechanical button/lever on the socket that releases the clip, ejecting the light bulb.



Case 6: Bow

In order to make products more inclusive, designers should allow for users to operate products with a single hand, rather than two. Consider the following actionfunction diagram of a typical bow. In using a typical bow, users must exert force with both arms to draw and steady the bow. Apply the corresponding design rule and develop a physical representation of the resulting product. The typical bow actionfunction diagram is provided below.



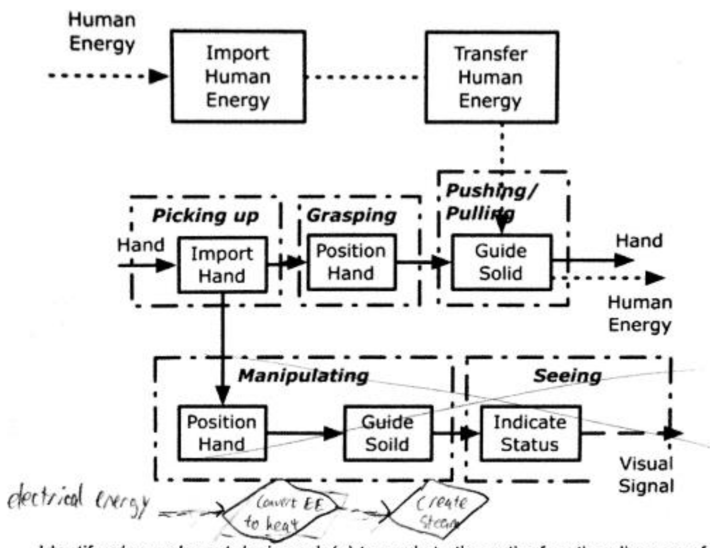
Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bow as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

design a base where the bow can be attached to a pivot point. The string can then be drawn with one hand and aimed by rotating about the pivot point.

attachment point that can pivot like a ball and socket joint.

Case 28: Clothes Iron

Designers should consider users with upper body disabilities, or otherwise reduced upper body strength, when developing products that require the user to pull and guide some portion of the product. By enacting some change, designers can alter the product so that the moving parts are no longer associated with a user activity, and are instead accomplished by the product itself. Consider a typical iron, for which the actionfunction diagram is provided below.

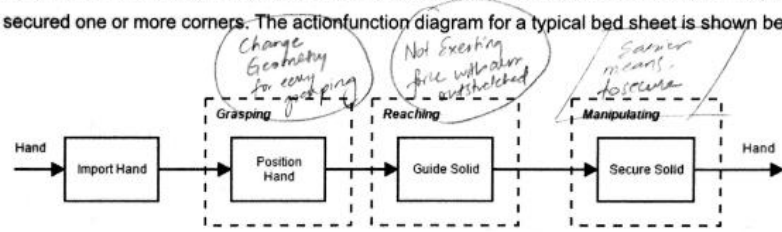


Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the clothes iron as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

make a chamber/container that clothing can be hung in and steam is generated. When the clothing is left in over night the wrinkles will "fall" out from the steam and gravity straightening the material out.

Case 1: Fitted Bed Sheets

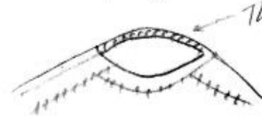
Users with diminished hand strength or dexterity, either due to age or injury, have trouble grasping products. Because they lack the necessary hand strength, users with impairments of the hand may not be able to maintain their grip on certain products as the user operates the product. In this case we consider the typical fitted bed sheet. In order to properly install the bed sheet, users must push and pull the sheet's edges around their mattress. Because fitted bed sheets contain elastic portions, it may be difficult for impaired users to pull the sheet after they have secured one or more corners. The actionfunction diagram for a typical bed sheet is shown below:



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the fitted sheets as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

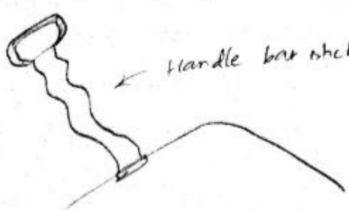
1.1) Grasping → Morphological → Easier

Thick edges with gaps so hands can grasp sheets.



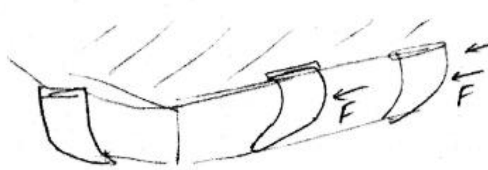
1.2) Reaching → Morphological → Not exerting with arm outstretched

Handle bar stiched to ends perhaps.



Case 1: Fitted Bed Sheets (continued)

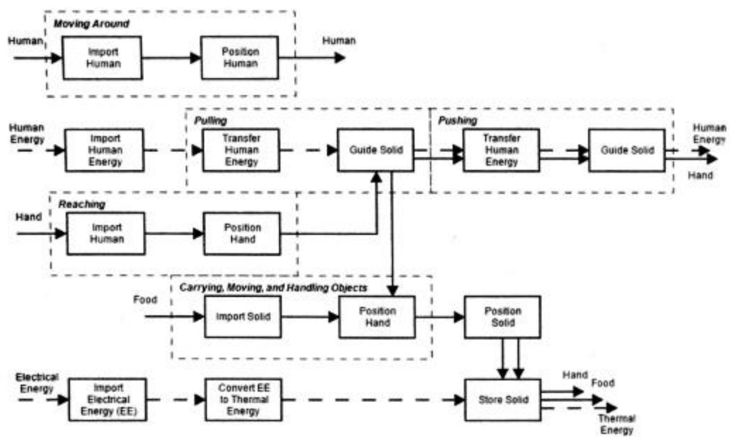
1.3) Manipulation → Parametric → Easier



Thick reinforced padding at the edges so pushed easily under the bed

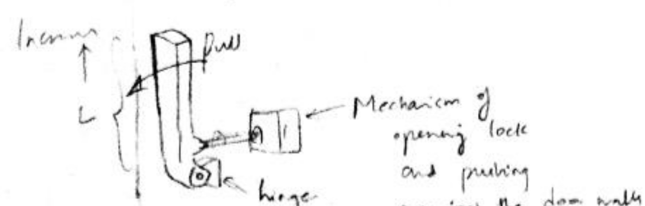
Case 2: Refrigerator Door Latch

Consider the typical refrigerator. Users with diminished strength may find the force requirements too high for breaking the seal and opening the refrigerator door. Refrigerator door seals are generally tight due to magnetic strips as well as the pressure differential between the cool air inside and the warm air outside. While users may still be able to open the door through considerable application of their force, it could be beneficial for designers to develop a more easy to open refrigerator for persons suffering from arthritis, injuries, or other debilitating conditions. The actionfunction diagram for a refrigerator is provided below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the refrigerator as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

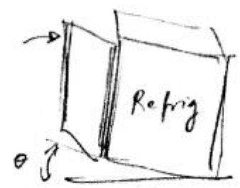
2.1) Pulling → Parametric → Easier
Change lever condition and length of handle bar lever



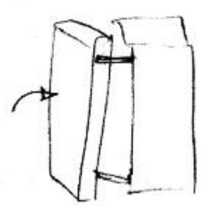
Case 2: Refrigerator Door Latch (continued)

2.2) Pushing → Morphological → No activity

Change shape or orientation of door so it closes by itself



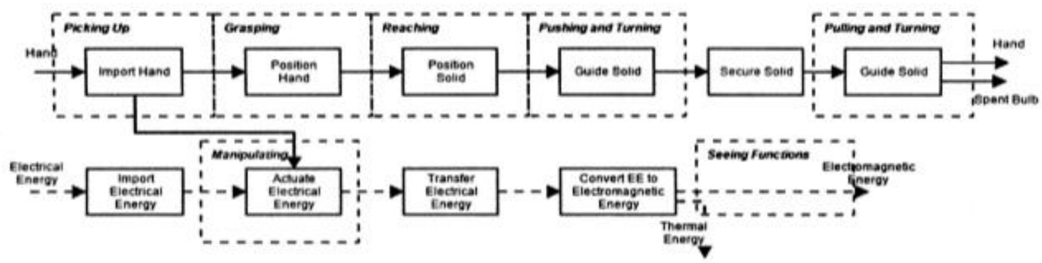
by gravity the door closes back



Angled hinges so door closes due to unbalanced weight.

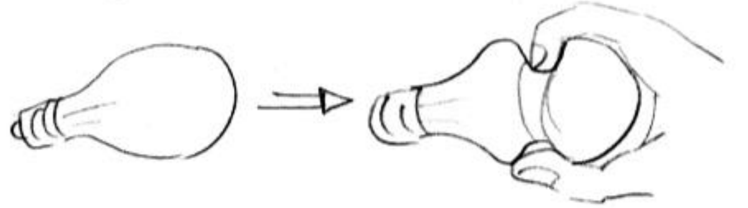
Case 3: Light Bulb

Users with diminished hand strength may have difficulties performing activities that require simultaneous manipulations. A classic example of a product that requires simultaneous manipulations is the child-proof pill bottle cap, which requires users to push and twist at the same time to disengage the cap. Many users have difficulty opening a pill bottle, which has led to many inclusive design alternatives, such as arthritis-friendly bottle caps. A lesser considered product that requires simultaneous manipulations is a lightbulb, as users must push and turn the lightbulb in order to install it. The actionfunction diagram for a light bulb is provided below.



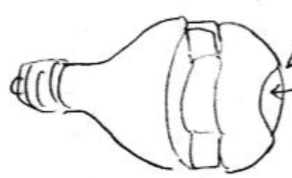
Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the light bulb as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

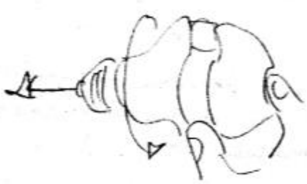
3.1) Grasping → Secure hand → functional → Easier



Case 3: Light Bulb (continued)

3.2) Pushing and turning → Guide solid → Easier
(fingers)

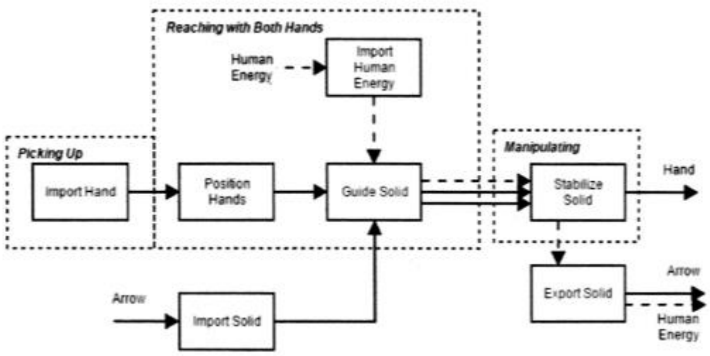




Using dimple as point of pressure and ribs to rotate bulb

Case 6: Bow

In order to make products more inclusive, designers should allow for users to operate products with a single hand, rather than two. Consider the following actionfunction diagram of a typical bow. In using a typical bow, users must exert force with both arms to draw and steady the bow. Apply the corresponding design rule and develop a physical representation of the resulting product. The typical bow actionfunction diagram is provided below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bow as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

6.1) Reaching with Both hands → Position hand → Morphological → Reach with Single arm

handle bar →

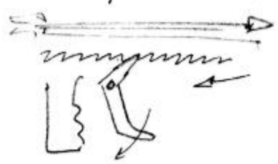
6.2) Reaching with both hands → Guide solid → Morphological → Not exerting force with arm outstretched

Magazine design

Case 6: Bow (continued)

6.3) Handling objects → Transfer human energy → Functional → Easier.

Rack and pinion with a stopper



Single hand cranking of tension on bow string.

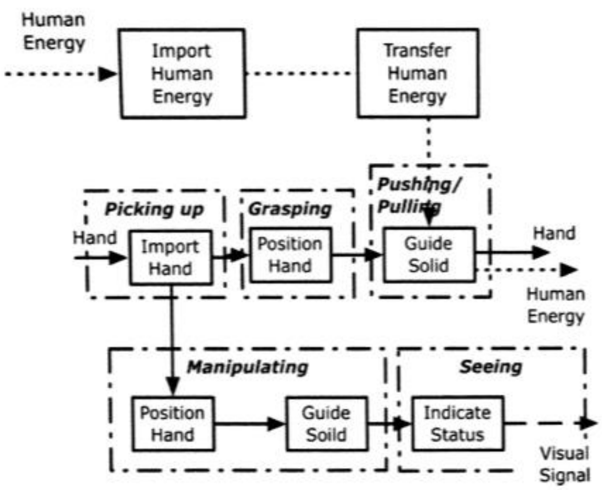
6.4) Manipulating → Morphological → Easier

Incorporate a stock butt for stabilisation.

Bring c.g to rear by stock butt.

Case 28: Clothes Iron

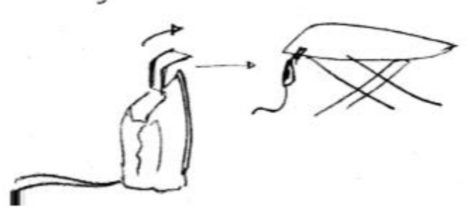
Designers should consider users with upper body disabilities, or otherwise reduced upper body strength, when developing products that require the user to pull and guide some portion of the product. By enacting some change, designers can alter the product so that the moving parts are no longer associated with a user activity, and are instead accomplished by the product itself. Consider a typical iron, for which the actionfunction diagram is provided below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the clothes iron as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

28.1) Picking up → Functional → Easier, Carrying moving, and handling objects

A hinge that can be ochuated by tilting Iron vertically

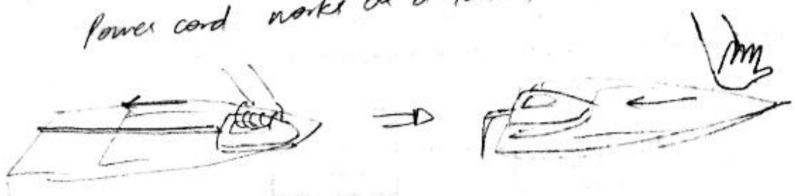


Elimination of picking up.

Case 28: Clothes Iron (continued)

28.2) Pushing / Pulling → Guide Solid → Parametric → Easier

Power cord works as a tension cord



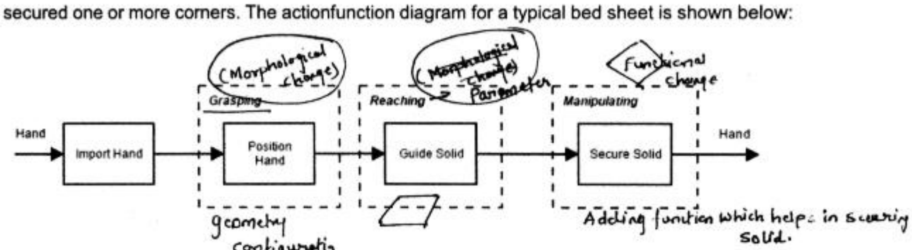
28.3) Seeing functions → Parametric → Easier

Color code for different temp

Red → Jeans
Green → Silk
Blue → x
Yellow → y

Case 1: Fitted Bed Sheets

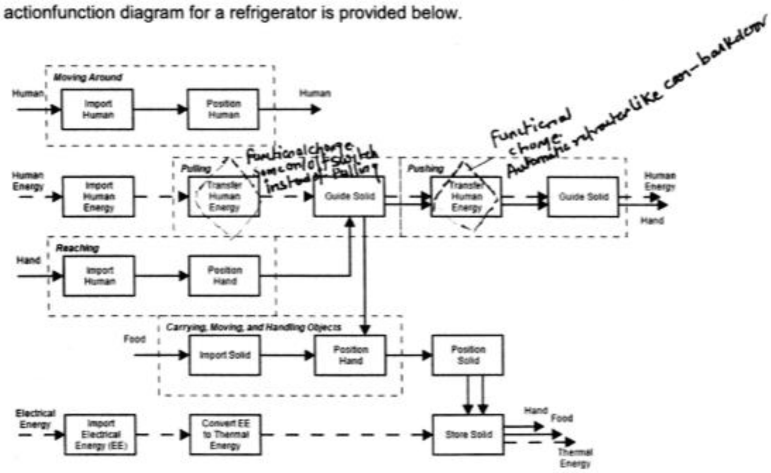
Users with diminished hand strength or dexterity, either due to age or injury, have trouble grasping products. Because they lack the necessary hand strength, users with impairments of the hand may not be able to maintain their grip on certain products as the user operates the product. In this case we consider the typical fitted bed sheet. In order to properly install the bed sheet, users must push and pull the sheet's edges around their mattress. Because fitted bed sheets contain elastic portions, it may be difficult for impaired users to pull the sheet after they have secured one or more corners. The actionfunction diagram for a typical bed sheet is shown below:



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the fitted sheets as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Case 2: Refrigerator Door Latch

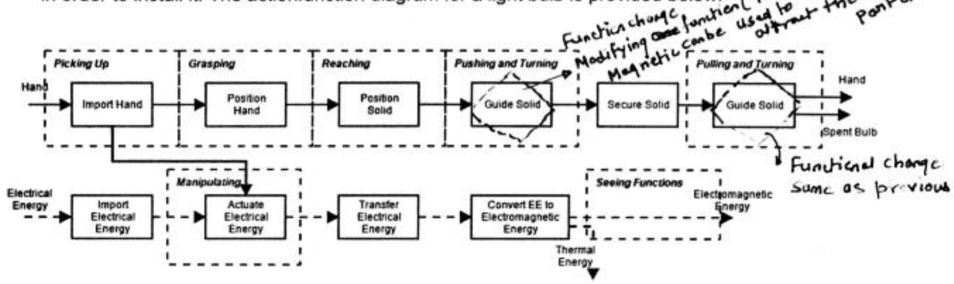
Consider the typical refrigerator. Users with diminished strength may find the force requirements too high for breaking the seal and opening the refrigerator door. Refrigerator door seals are generally tight due to magnetic strips as well as the pressure differential between the cool air inside and the warm air outside. While users may still be able to open the door through considerable application of their force, it could be beneficial for designers to develop a more easy to open refrigerator for persons suffering from arthritis, injuries, or other debilitating conditions. The actionfunction diagram for a refrigerator is provided below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the refrigerator as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Case 3: *Light Bulb*

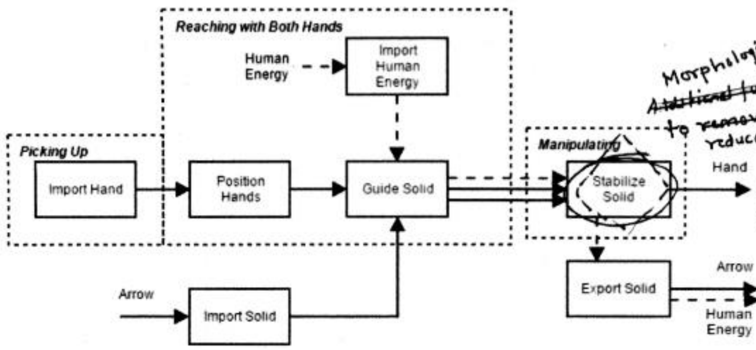
Users with diminished hand strength may have difficulties performing activities that require simultaneous manipulations. A classic example of a product that requires simultaneous manipulations is the child-proof pill bottle cap, which requires users to push and twist at the same time to disengage the cap. Many users have difficulty opening a pill bottle, which has led to many inclusive design alternatives, such as arthritis-friendly bottle caps. A lesser considered product that requires simultaneous manipulations is a lightbulb, as users must push and turn the lightbulb in order to install it. The actionfunction diagram for a light bulb is provided below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the light bulb as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Case 6: Bow

In order to make products more inclusive, designers should allow for users to operate products with a single hand, rather than two. Consider the following actionfunction diagram of a typical bow. In using a typical bow, users must exert force with both arms to draw and steady the bow. Apply the corresponding design rule and develop a physical representation of the resulting product. The typical bow actionfunction diagram is provided below.

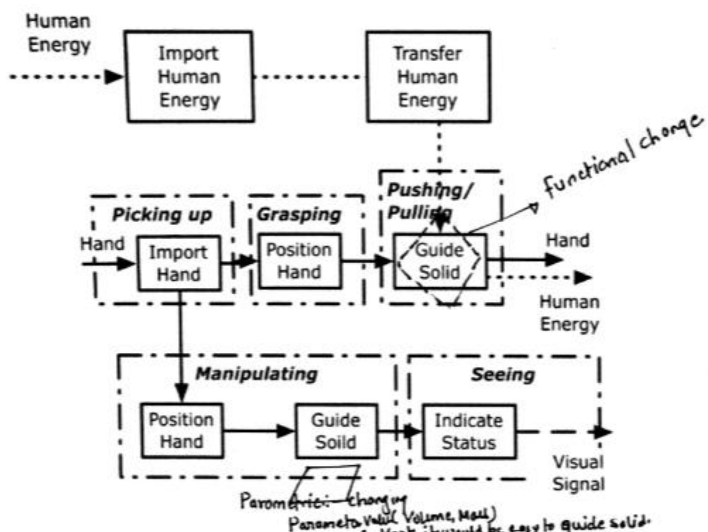


Morphological change
~~Additional function~~
to ~~remove~~ reduce user efforts applied by both hand.
Fixing one Part (solid Part) to something so that User has to apply force on one arrow only

Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bow as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Case 28: Clothes Iron

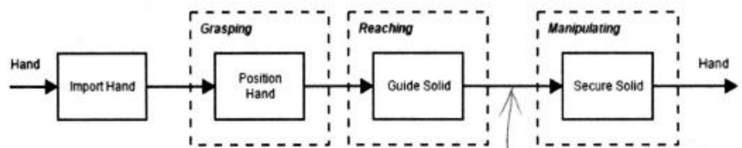
Designers should consider users with upper body disabilities, or otherwise reduced upper body strength, when developing products that require the user to pull and guide some portion of the product. By enacting some change, designers can alter the product so that the moving parts are no longer associated with a user activity, and are instead accomplished by the product itself. Consider a typical iron, for which the actionfunction diagram is provided below.



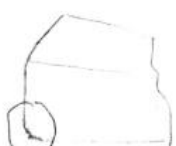
Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the clothes iron as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Case 1: Fitted Bed Sheets

Users with diminished hand strength or dexterity, either due to age or injury, have trouble grasping products. Because they lack the necessary hand strength, users with impairments of the hand may not be able to maintain their grip on certain products as the user operates the product. In this case we consider the typical fitted bed sheet. In order to properly install the bed sheet, users must push and pull the sheet's edges around their mattress. Because fitted bed sheets contain elastic portions, it may be difficult for impaired users to pull the sheet after they have secured one or more corners. The actionfunction diagram for a typical bed sheet is shown below:



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the fitted sheets as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).



easy to stretch, rubber band included

Manipulating

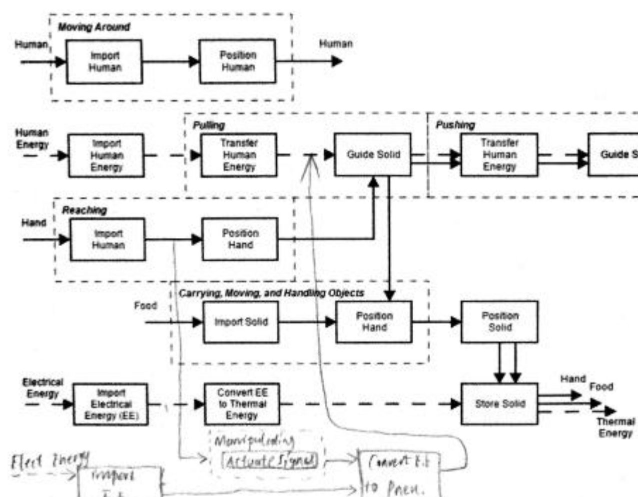
$\boxed{\text{Guide Solid}}$

I use "Manipulating – Guide Solid – Parametric" to redesign the bed sheet there are four pieces of rubber band installed in four corners of the bed sheet for

So, after the sheet is guided to proper location, the disabled could easily tuck the sheet under the mattress. So, there is no need to use much strength to do that, with fingers moving along mattress side, you can do it .

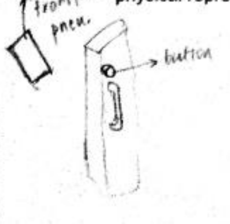
Case 2: *Refrigerator Door Latch*

Consider the typical refrigerator. Users with diminished strength may find the force requirements too high for breaking the seal and opening the refrigerator door. Refrigerator door seals are generally tight due to magnetic strips as well as the pressure differential between the cool air inside and the warm air outside. While users may still be able to open the door through considerable application of their force, it could be beneficial for designers to develop a more easy to open refrigerator for persons suffering from arthritis, injuries, or other debilitating conditions. The actionfunction diagram for a refrigerator is provided below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the refrigerator as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

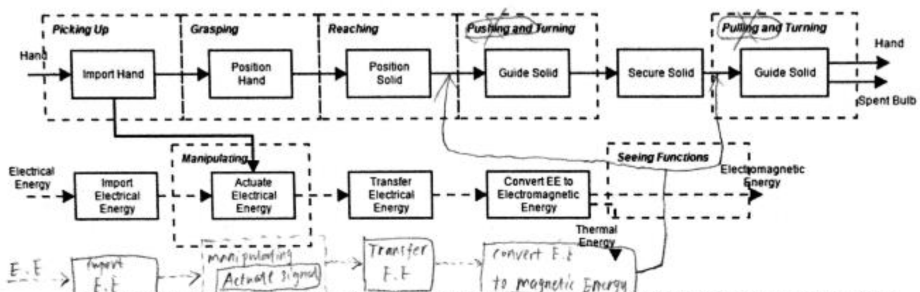
machine which can transfer e.e to pneu.



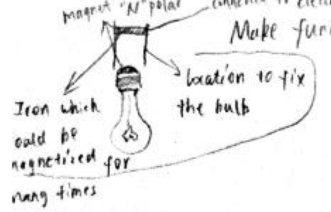
I add a button on the top of the handle, when the disabled want to pull the door open. they push the button and the machine could convert electrical energy to pneumatic energy so that inner high pressure can "help" to open the door.

Case 3: ***Light Bulb***

Users with diminished hand strength may have difficulties performing activities that require simultaneous manipulations. A classic example of a product that requires simultaneous manipulations is the child-proof pill bottle cap, which requires users to push and twist at the same time to disengage the cap. Many users have difficulty opening a pill bottle, which has led to many inclusive design alternatives, such as arthritis-friendly bottle caps. A lesser considered product that requires simultaneous manipulations is a lightbulb, as users must push and turn the lightbulb in order to install it. The actionfunction diagram for a light bulb is provided below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the light bulb as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

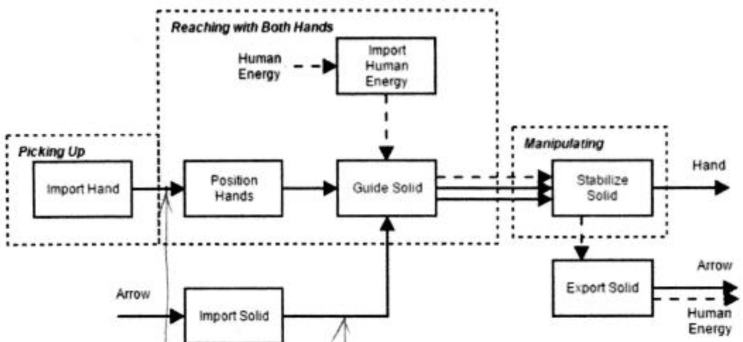


Make functional changes to make the bulb easier to be installed and detached

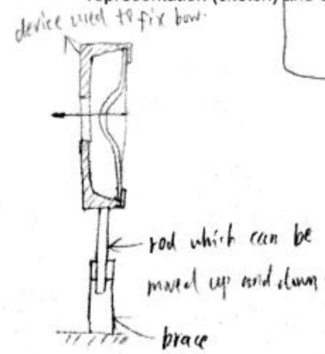
As we know, some kinds of Iron could be magnetized when connected to electricity. So the inspiration comes from this, using magnetic energy to provide energy otherwise provided by human. (pushing or pulling)

Case 6: *Bow*

In order to make products more inclusive, designers should allow for users to operate products with a single hand, rather than two. Consider the following actionfunction diagram of a typical bow. In using a typical bow, users must exert force with both arms to draw and steady the bow. Apply the corresponding design rule and develop a physical representation of the resulting product. The typical bow actionfunction diagram is provided below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bow as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).



Manipulating
Guide Solid

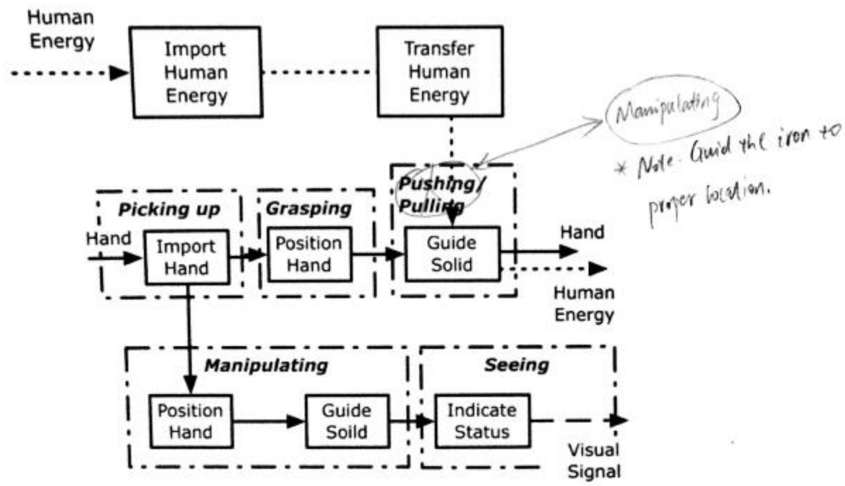
(*) Note: moving the bow around the device used to fix the bow

I make (add) a functional change to the bow system.

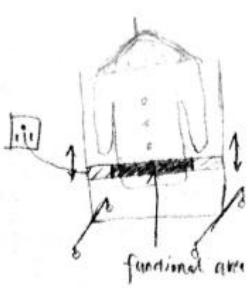
By virtue of the device to fix the bow, we can eject the arrow with only one hand occupied

Case 28: *Clothes Iron*

Designers should consider users with upper body disabilities, or otherwise reduced upper body strength, when developing products that require the user to pull and guide some portion of the product. By enacting some change, designers can alter the product so that the moving parts are no longer associated with a user activity, and are instead accomplished by the product itself. Consider a typical iron, for which the actionfunction diagram is provided below. 5



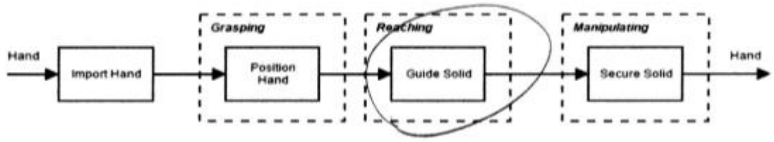
Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the clothes iron as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).



I make parametric changes to the clothes iron, making it be rectangular and be easily settled on the two-side supporter. If we want to flatten or soften some parts on the clothes, we just change the position of the modified clothes iron

Case 1: Fitted Bed Sheets

Users with diminished hand strength or dexterity, either due to age or injury, have trouble grasping products. Because they lack the necessary hand strength, users with impairments of the hand may not be able to maintain their grip on certain products as the user operates the product. In this case we consider the typical fitted bed sheet. In order to properly install the bed sheet, users must push and pull the sheet's edges around their mattress. Because fitted bed sheets contain elastic portions, it may be difficult for impaired users to pull the sheet after they have secured one or more corners. The actionfunction diagram for a typical bed sheet is shown below:



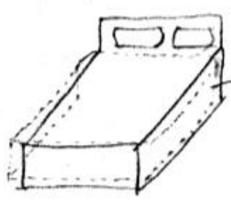
Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the fitted sheets as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Reaching

Guide Solid

Apply morphological change

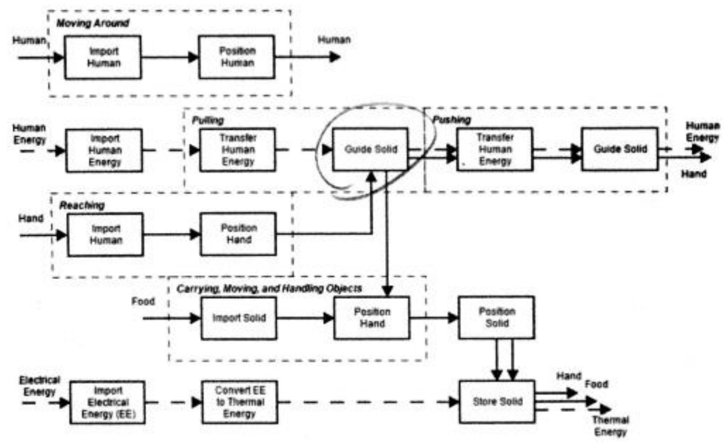
Change the material of the bed sheets; remove the elastic portion to let user use less force to stretch it



remove the elastic portion

Case 2: ***Refrigerator Door Latch***

Consider the typical refrigerator. Users with diminished strength may find the force requirements too high for breaking the seal and opening the refrigerator door. Refrigerator door seals are generally tight due to magnetic strips as well as the pressure differential between the cool air inside and the warm air outside. While users may still be able to open the door through considerable application of their force, it could be beneficial for designers to develop a more easy to open refrigerator for persons suffering from arthritis, injuries, or other debilitating conditions. The actionfunction diagram for a refrigerator is provided below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the refrigerator as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Pulling Apply morphological change

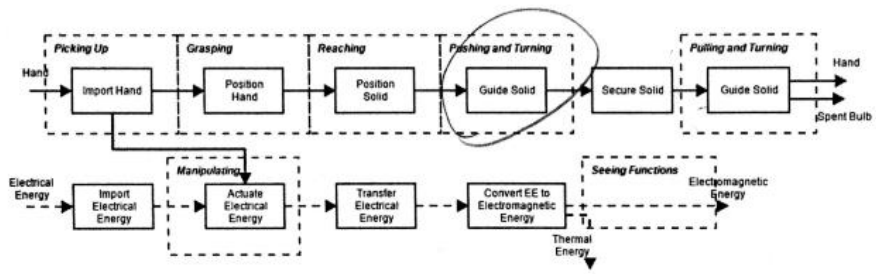
Guide Solid

change the way of opening the door from using bare hands to electronical control system. User push a button to automatically open the door

button to be pushed to open the door

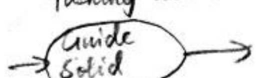
Case 3: *Light Bulb*

Users with diminished hand strength may have difficulties performing activities that require simultaneous manipulations. A classic example of a product that requires simultaneous manipulations is the child-proof pill bottle cap, which requires users to push and twist at the same time to disengage the cap. Many users have difficulty opening a pill bottle, which has led to many inclusive design alternatives, such as arthritis-friendly bottle caps. A lesser considered product that requires simultaneous manipulations is a lightbulb, as users must push and turn the lightbulb in order to install it. The actionfunction diagram for a light bulb is provided below.

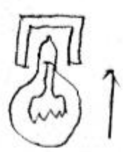


Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the light bulb as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Pushing and turning   Apply morphological change



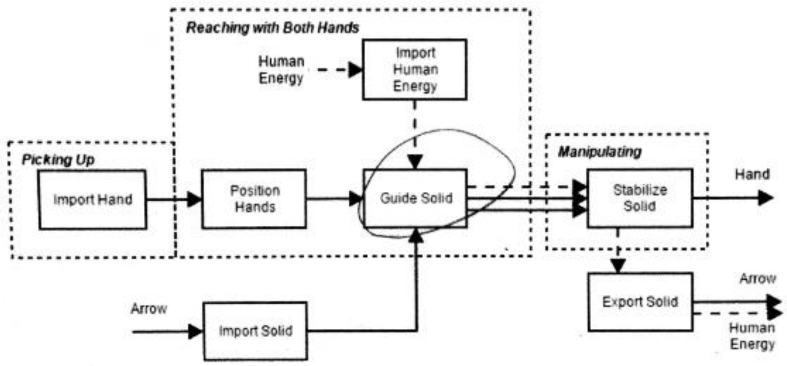
Change the way how to secure the bulb from using the screw thread to inserting.



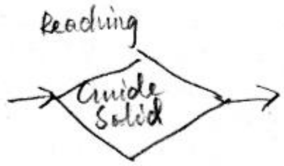
insert to secure mechanism
no turning

Case 6: Bow

In order to make products more inclusive, designers should allow for users to operate products with a single hand, rather than two. Consider the following actionfunction diagram of a typical bow. In using a typical bow, users must exert force with both arms to draw and steady the bow. Apply the corresponding design rule and develop a physical representation of the resulting product. The typical bow actionfunction diagram is provided below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bow as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

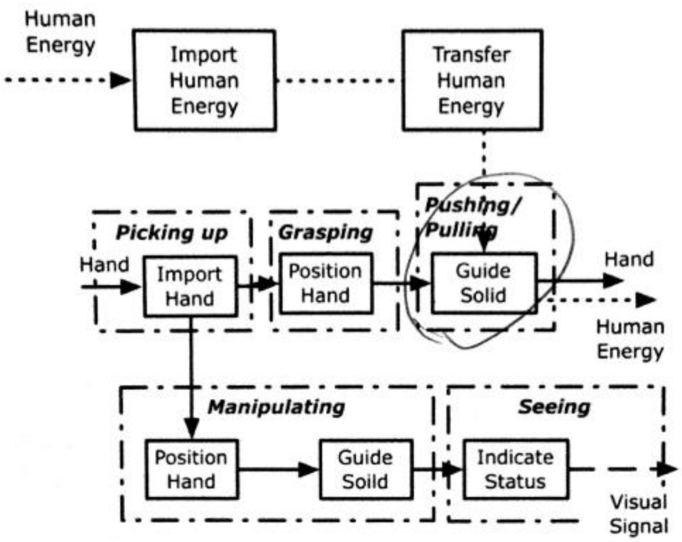


Apply function change.

stock to secure the bow first and only require one hand to pull the string

Case 28: Clothes Iron

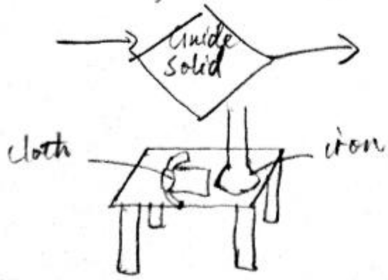
Designers should consider users with upper body disabilities, or otherwise reduced upper body strength, when developing products that require the user to pull and guide some portion of the product. By enacting some change, designers can alter the product so that the moving parts are no longer associated with a user activity, and are instead accomplished by the product itself. Consider a typical iron, for which the actionfunction diagram is provided below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the clothes iron as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Pushing and Pulling

Apply function change



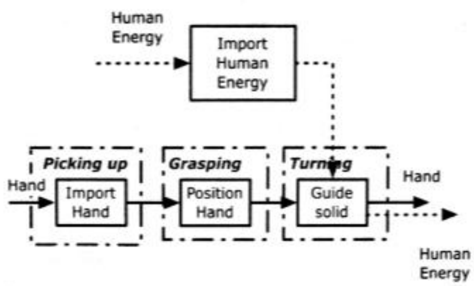
Change the iron from manual one to automatical one. The iron will move itself among the clothes that is fixed on the table. This action feature require power of electricity.

[redacted]
01

Case 4: Bottle Cap

Users with diminished dexterity may have difficulties utilizing a pincer grip to grasp objects, as is necessary when turning an object. Designers should consider modifying products that require turning to instead utilize a different user activity. A classic example of a product that requires gripping and turning is a twist-off bottle cap, such as one would find on a plastic water bottle. The actionfunction diagram for a plastic water bottle cap is pictured below.

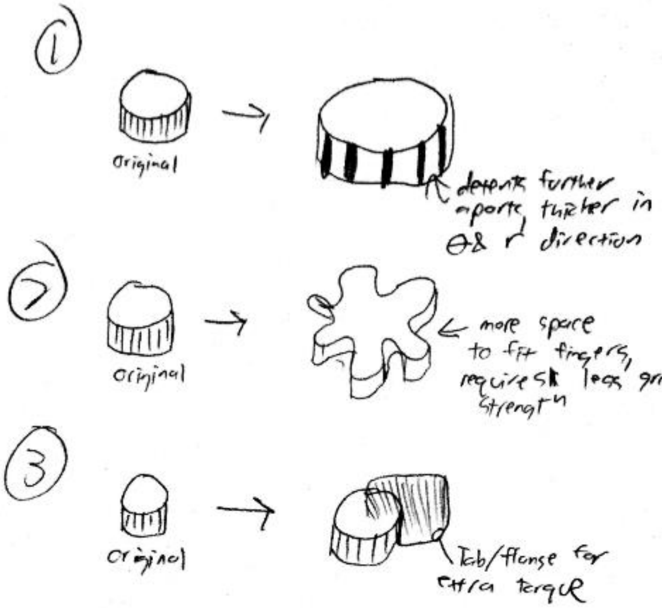
Typical bottle caps are threaded onto a receiving thread on the bottle, a cheap and reusable way of sealing the bottle. In developing a more inclusive product, we must also consider the marketability of the resulting product. Any new inclusive design should avoid increasing the cost or complexity of the system, so as to not inhibit its use.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bottle cap as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

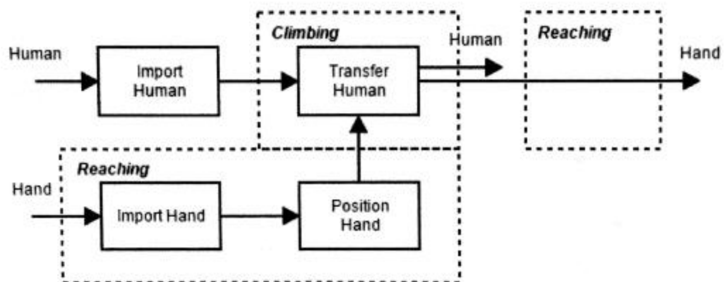
1. Grasping, position hand, parametric, easier → Larger cap, larger detents
2. Grasping, position hand, morphological, easier → make cap asymmetrical
3. Pulling, guide solid, morphological, no activity → asymmetrical cap with flange for leverage

Case 4: Bottle Cap (continued)



Case 7: Typical Ladder

Users with physical impairments may have reduced reach when compared to able users. Consider the typical ladder, which requires users to reach and exert force with outstretched arms when climbing. In order to make the ladder more inclusive, modifications should allow users to scale the ladder regardless of their reach capabilities. The actionfunction diagram for a typical ladder is pictured below.

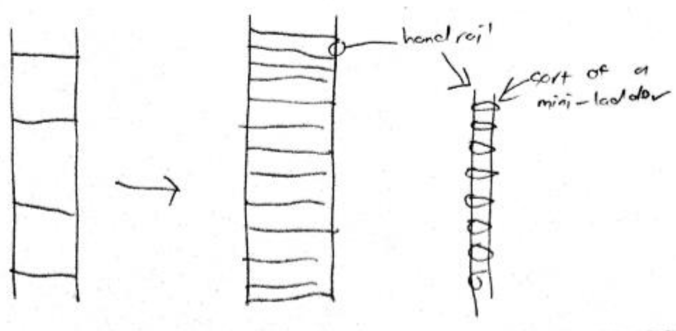


Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the typical ladder as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

(1) ~~Transferring oneself~~ Climbing, Import human, parametric, easier → smaller ladder step increments

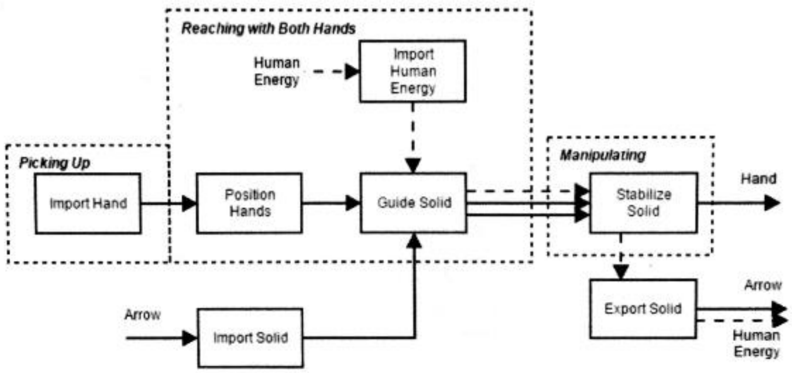
(2) Reaching, guide solid, morphological, not exerting force with arm outstretched → add hand ra along length

(3) Reaching, position hand, parametric, easier → easy to grasp hand rail



Case 8: *Bow*

Users with physical impairments have difficulty exerting force with their arms extended. Consider the typical bow. While not typically associated with disabled users, archery is a sport many enjoy. Less able users would have difficulty drawing and steadying a typical bow, as they may not be strong enough to exert force with an outstretched arm.

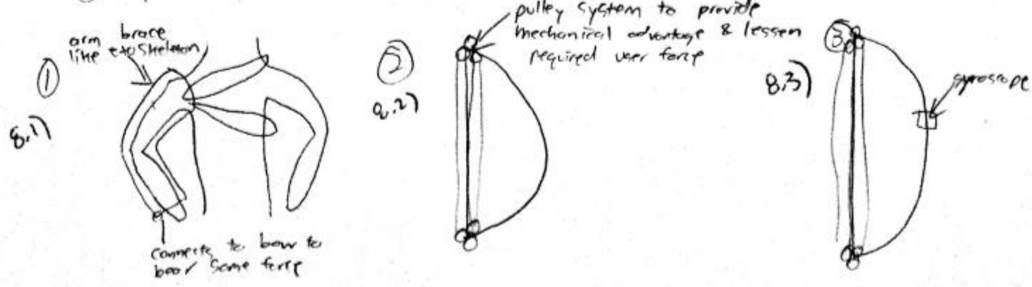


Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bow as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

(1) Reaching, guide solid, morphological, not exerting force with arm outstretched → full arm brace mech advantage

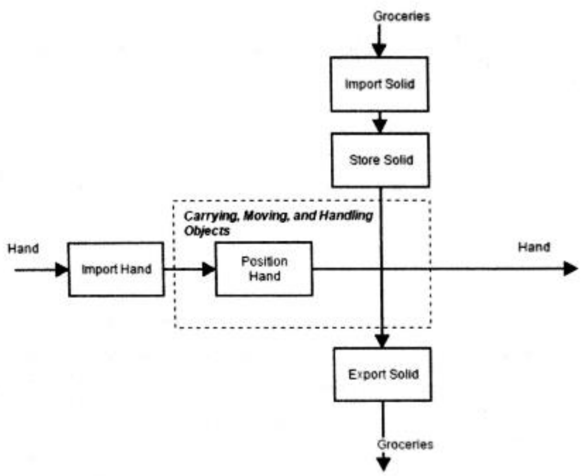
(2) Carrying, moving, & handling objects, transfer human energy, functional, easier, lower force → pulley system to reduce user force

(3) Manipulating, guide solid, morphological, easier → gyroscopic stabilization



Case 22: *Grocery Bags*

In order to make environments and products more accessible to all users, designers should consider changes to how a user positions their hands on the product to move or otherwise handle the object. Users with upper body disabilities will have difficulty grasping or carrying certain shapes of objects, so designers should consider changes in order to develop more inclusive products. A relevant product is a typical grocery bag. Users with hand impairments may not have the dexterity or strength required to properly carry the bag. Handling the grocery bag may be difficult for various reasons. The handles are narrow and do not provide much room for gripping, likewise the handles are not made of substantial material and may deform, tear, or cut into the user's hand.

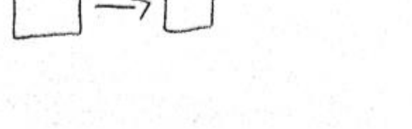


Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the grocery bags as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

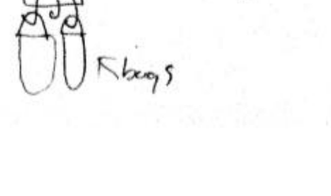
(1) Carrying, moving, handling objects, position hand, parametric, easier → wider handles for more surface area, stiffer/more durable material.

(2) Grasping, position hand, morphological, easier → intermediary object to support bags that is gripped by user.

22.1) (1)

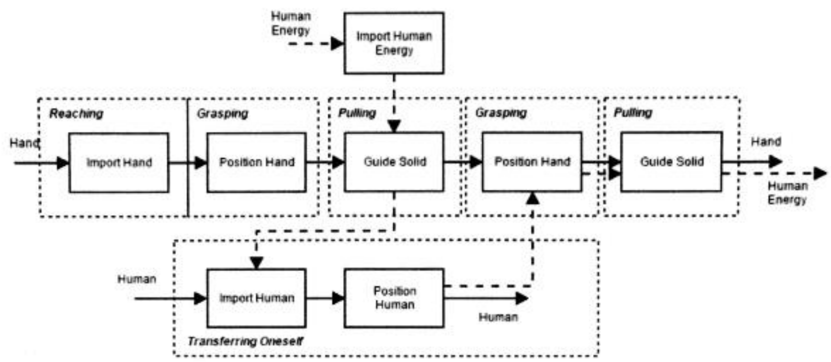


(2) 22.2)



Case 32: Car Doors

Designers should consider users with diminished mobility when designing the access points for products and environments. Users with mobility impairments will have trouble transferring themselves into the car through the car door unassisted, as they may lack the coordination or strength necessary to pull themselves into the car. The figure below shows the actionfunction diagram for a typical car door.



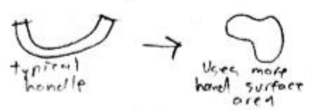
Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the car door as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

① Grasping, position hand, parametric, easier → handle that does not require large amounts grip strength, uses more of hand surface are

② Pulling, guide solid, morphological, no activity → grip provides force to pull user into car

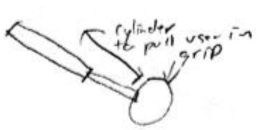
③ Transferring oneself, import human, morphological, better → see above where car pulls human in

32.1) ①



③ Same as ②

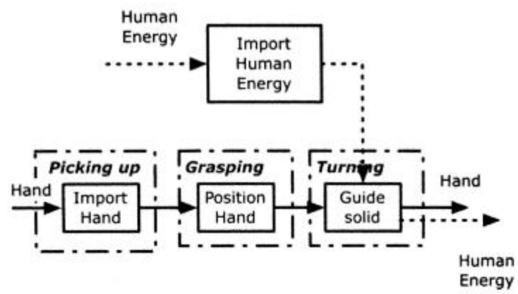
32.2) ②



Case 4: Bottle Cap

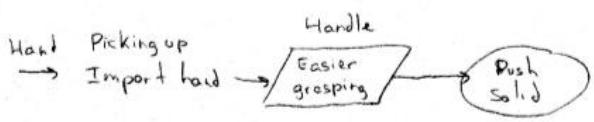
Users with diminished dexterity may have difficulties utilizing a pincer grip to grasp objects, as is necessary when turning an object. Designers should consider modifying products that require turning to instead utilize a different user activity. A classic example of a product that requires gripping and turning is a twist-off bottle cap, such as one would find on a plastic water bottle. The actionfunction diagram for a plastic water bottle cap is pictured below.

Typical bottle caps are threaded onto a receiving thread on the bottle, a cheap and reusable way of sealing the bottle. In developing a more inclusive product, we must also consider the marketability of the resulting product. Any new inclusive design should avoid increasing the cost or complexity of the system, so as to not inhibit its use.



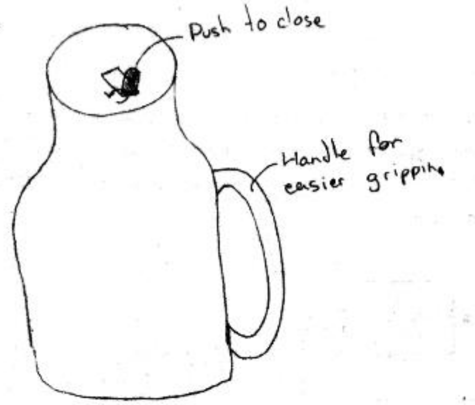
Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bottle cap as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

In order to make the cap easier to grab one could add little supports on a ~~th~~ handle to allow for grasping with one or two fingers, or a prosthetic hand. Instead of turning, use the principle of "pushing with hands to seal bottle (paramet change)



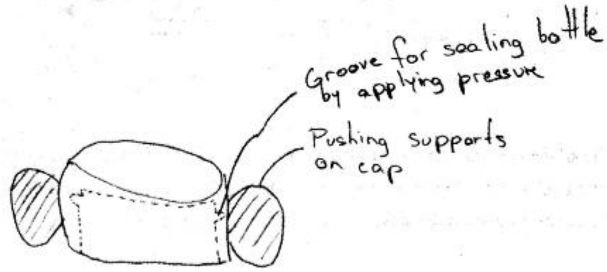
Case 4: Bottle Cap (continued)

4.1)



Option 1

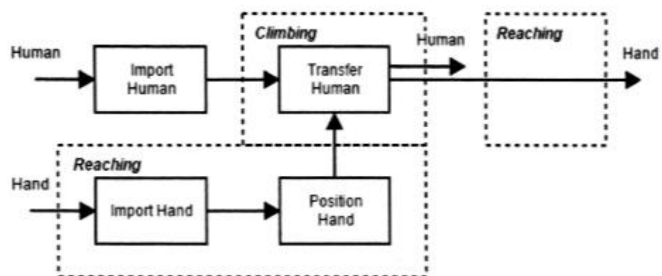
4.2)



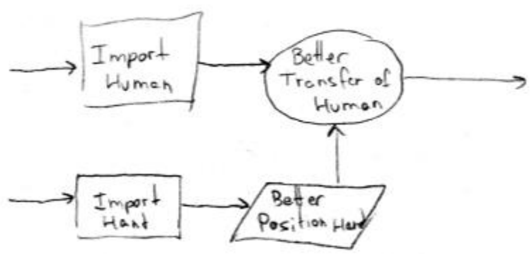
Option 2

Case 7: Typical Ladder

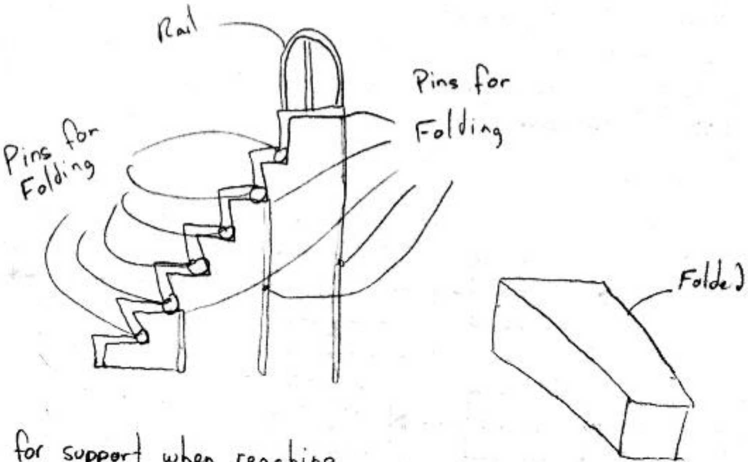
Users with physical impairments may have reduced reach when compared to able users. Consider the typical ladder, which requires users to reach and exert force with outstretched arms when climbing. In order to make the ladder more inclusive, modifications should allow users to scale the ladder regardless of their reach capabilities. The actionfunction diagram for a typical ladder is pictured below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the typical ladder as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).



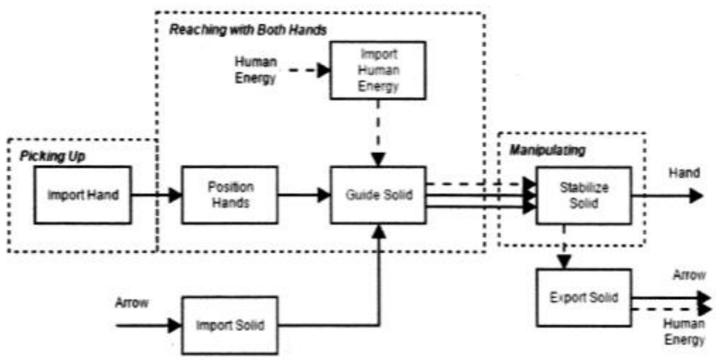
Case 7: Typical Ladder (continued)



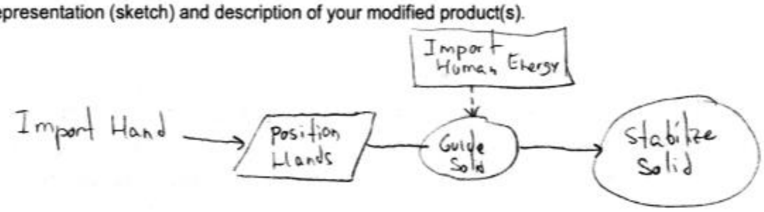
Rail allows for support when reaching

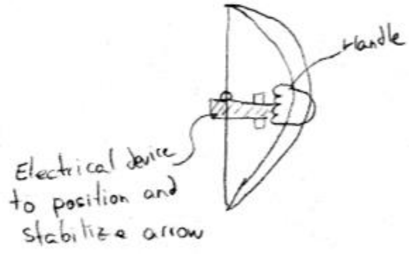
Case 8: Bow

Users with physical impairments have difficulty exerting force with their arms extended. Consider the typical bow. While not typically associated with disabled users, archery is a sport many enjoy. Less able users would have difficulty drawing and steadying a typical bow, as they may not be strong enough to exert force with an outstretched arm.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bow as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).



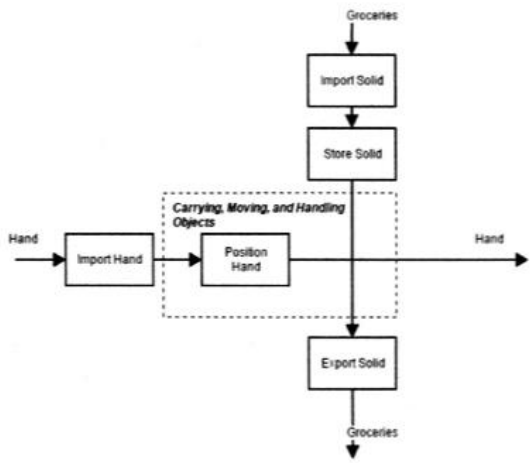


Handle aids in grasping

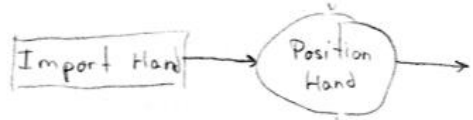
Electrical device grips arrow and pulls string tight. User may then release arrow by pulling string side ways, or presing a button on the side of the handle

Case 22: Grocery Bags

In order to make environments and products more accessible to all users, designers should consider changes to how a user positions their hands on the product to move or otherwise handle the object. Users with upper body disabilities will have difficulty grasping or carrying certain shapes of objects, so designers should consider changes in order to develop more inclusive products. A relevant product is a typical grocery bag. Users with hand impairments may not have the dexterity or strength required to properly carry the bag. Handling the grocery bag may be difficult for various reasons. The handles are narrow and do not provide much room for gripping, likewise the handles are not made of substantial material and may deform, tear, or cut into the user's hand.

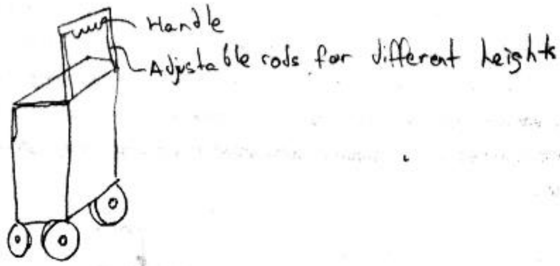


Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the grocery bags as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).



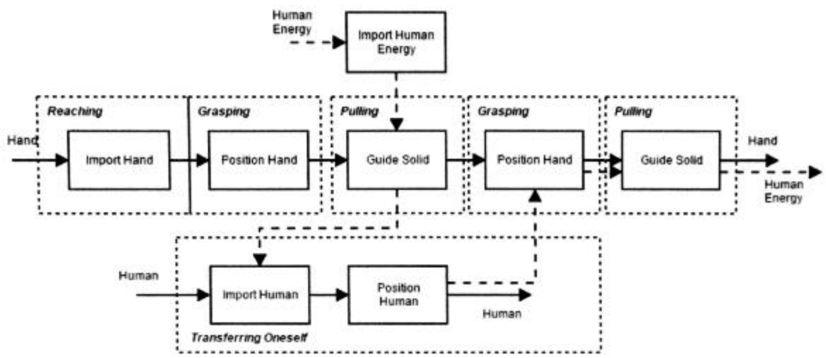
Case 22: Grocery Bags (continued)

Transform Bag into Cart to eliminate requirement of carrying weight and eliminate gripping limitation

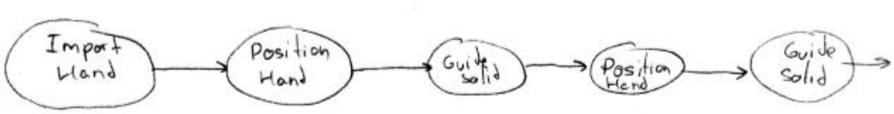


Case 32: Car Doors

Designers should consider users with diminished mobility when designing the access points for products and environments. Users with mobility impairments will have trouble transferring themselves into the car through the car door unassisted, as they may lack the coordination or strength necessary to pull themselves into the car. The figure below shows the actionfunction diagram for a typical car door.

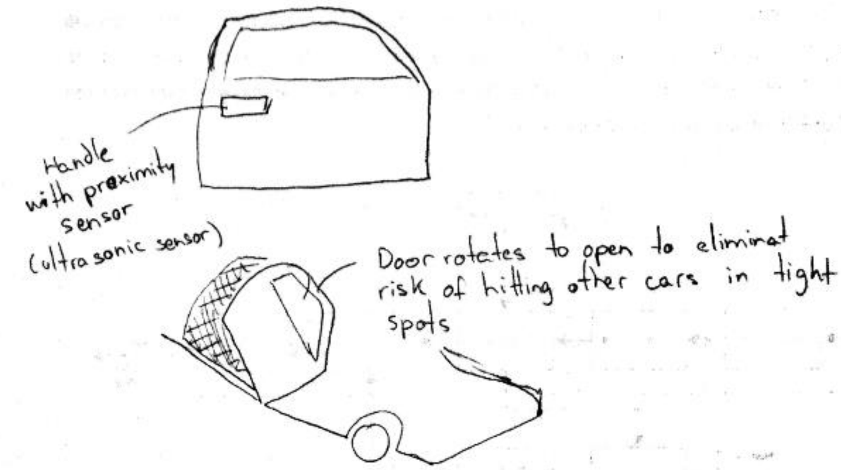


Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the car door as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).



Fully automate door to open & close with the push of a button, or by placing hand near door handle when keychain/bundle is in the vicinity of the car; much like a Tesla vehicle

Case 32: Car Doors (continued)



Case 4: Bottle Cap

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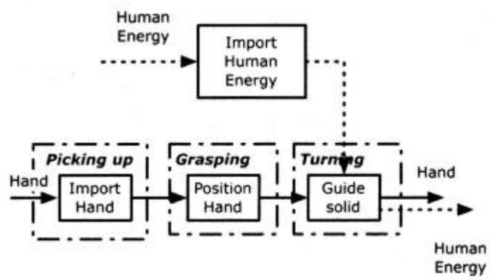
Typical bottle caps are threaded onto a receiving thread on the bottle, a cheap and reusable way of sealing the bottle. In developing a more inclusive product, we must also consider the marketability of the resulting product. Any new inclusive design should avoid increasing the cost or complexity of the system, so as to not inhibit its use.



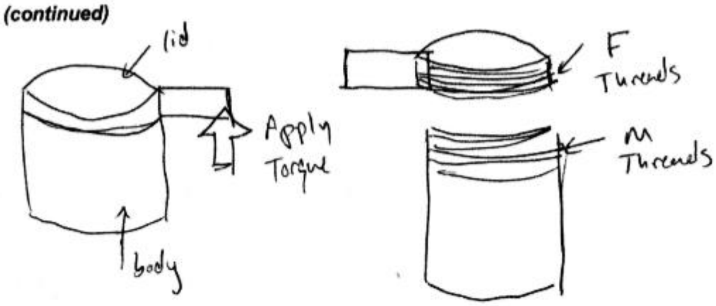
Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bottle cap as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Main Problems: Grasping - Position Hand → Parametric; make task easier
Turning - Guide Solid → Morphological; push with hand.

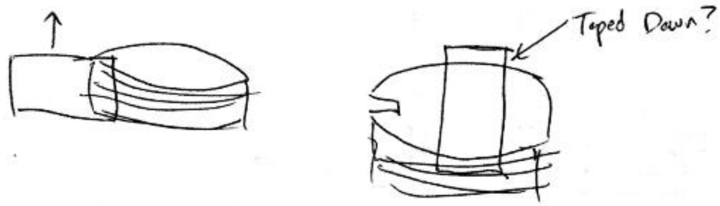
Idea: Cans are increasingly replacing models. They have the additional advantage that the "lid" is as large as the rest of the body. This already makes the product easier to handle. There is also a great analogy in faucet handles which have evolved from pincer-turning to pushing a handle.

Case 4: Bottle Cap (continued)

New Design

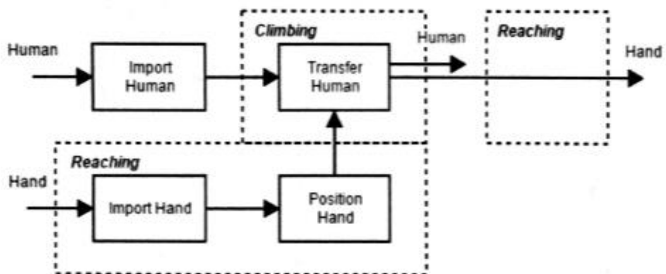


The tab is kind of inconvenient, allow it to slide out for easy packaging



Case 7: Typical Ladder

Users with physical impairments may have reduced reach when compared to able users. Consider the typical ladder, which requires users to reach and exert force with outstretched arms when climbing. In order to make the ladder more inclusive, modifications should allow users to scale the ladder regardless of their reach capabilities. The actionfunction diagram for a typical ladder is pictured below.

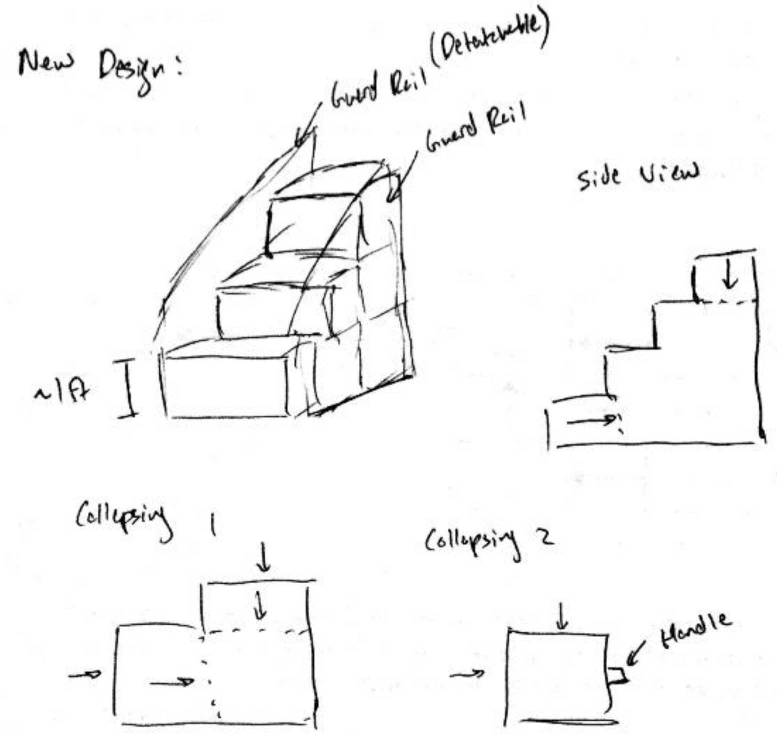


Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the typical ladder as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Main Problems: Transferring oneself - Import Human? → { Morph. - Better / Par. - Easier }
Reaching - Position ~~the~~ hand → Parametric - Easier

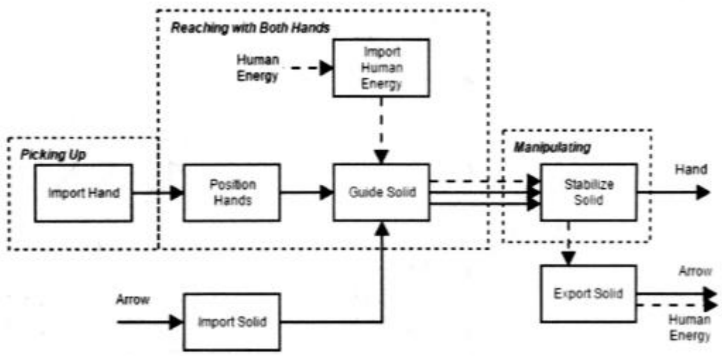
Idea: Make more like staircase so all climbing comes from legs.
The staircase can collapse into a single box (to match ladder advantage of portability/collapsible)

Case 7: Typical Ladder (continued)



Case 8: Bow

Users with physical impairments have difficulty exerting force with their arms extended. Consider the typical bow. While not typically associated with disabled users, archery is a sport many enjoy. Less able users would have difficulty drawing and steadying a typical bow, as they may not be strong enough to exert force with an outstretched arm.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bow as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Main Problems: Reaching - Guide Solid → Morph. ; Not exerting force w/ outstretched arms

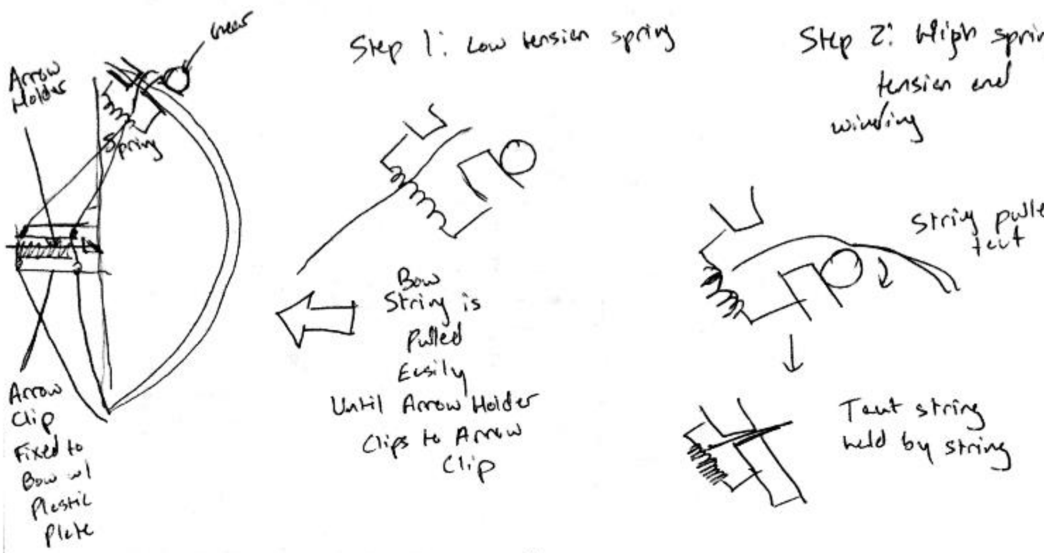
Pulling - Guide Solid → Parametric; Easier

Design Idea: Allow user to pull back string and load arrow with much less force. The bow itself creates the extra tension.

In first step, user loads arrow and pulls back string lightly. The arrow clicks in place. In second step, external gears put tension on string. Finally, user ~~[illegible]~~ fires arrow w/ trigger.

Case 8: Bow (continued)

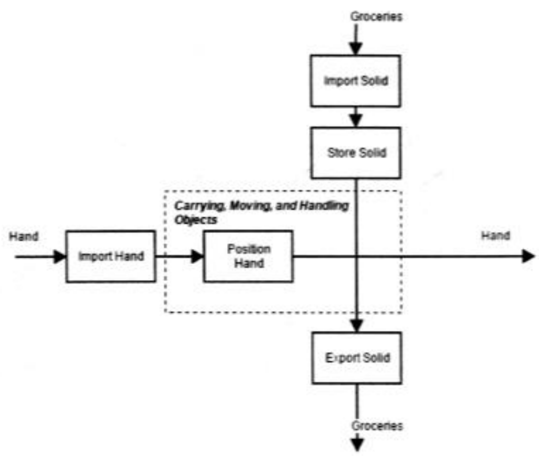
New Design:



etc.

Case 22: Grocery Bags

In order to make environments and products more accessible to all users, designers should consider changes to how a user positions their hands on the product to move or otherwise handle the object. Users with upper body disabilities will have difficulty grasping or carrying certain shapes of objects, so designers should consider changes in order to develop more inclusive products. A relevant product is a typical grocery bag. Users with hand impairments may not have the dexterity or strength required to properly carry the bag. Handling the grocery bag may be difficult for various reasons. The handles are narrow and do not provide much room for gripping, likewise the handles are not made of substantial material and may deform, tear, or cut into the user's hand.

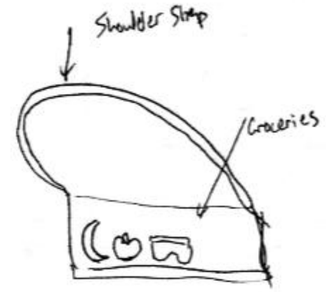


Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the grocery bags as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Main Problems: Position Hand - Grasping → Morph.; Easier
Carrying, Moving, Handling - Position Hand → Par; Easier

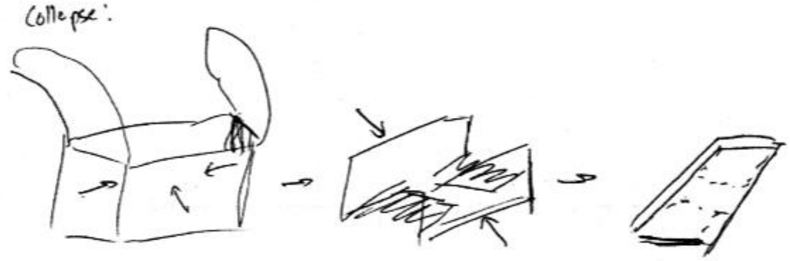
Design Idea: A collapsible box like a hot-dog vendor has. Weight is supported from bottom instead of top

Case 22: Grocery Bags (continued)



Weight is supported on shoulders, and grip is extended to whole bottom surface

Collapse:



Case 32: Car Doors

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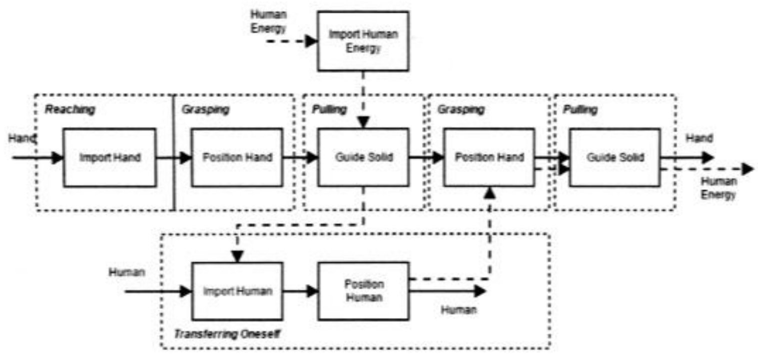
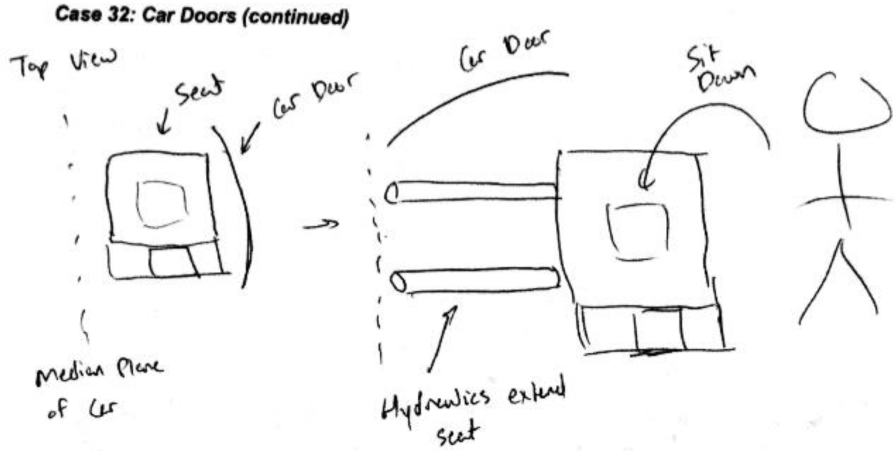


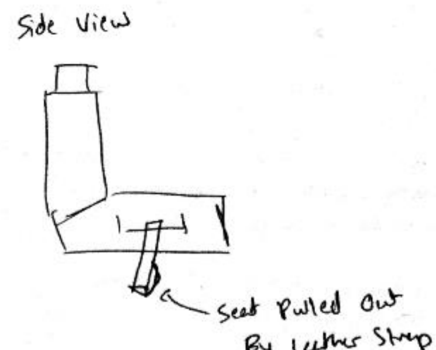
Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the car door as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Main Problems: Transferring oneself - Import Human → Morph, Better
Pulling - Guide Solid → Par.; Easier

Design Idea: Add sliding rails to seat, so seat can temporarily slide out of car. It is much easier to sit down directly instead of trying to support your weight while simultaneously sitting and moving translationally.

Case 32: Car Doors (continued)





Case 4: Bottle Cap

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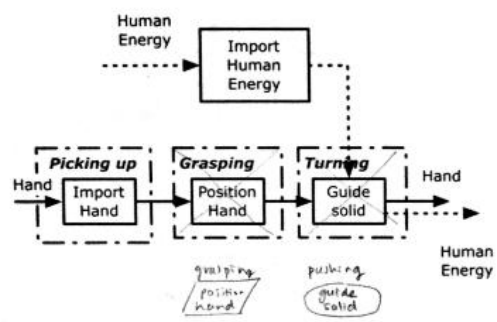
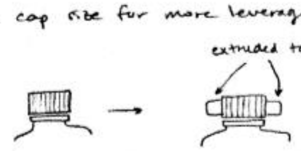


Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bottle cap as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

→ increase bottle cap size for more leverage

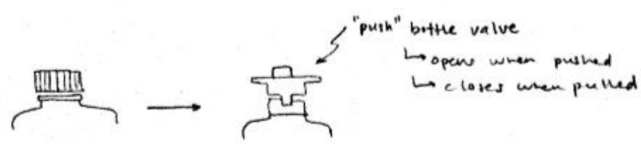
grasping
position hand

4.1)



pushing
guide solid
→

4.2)



Case 7: *Typical Ladder*

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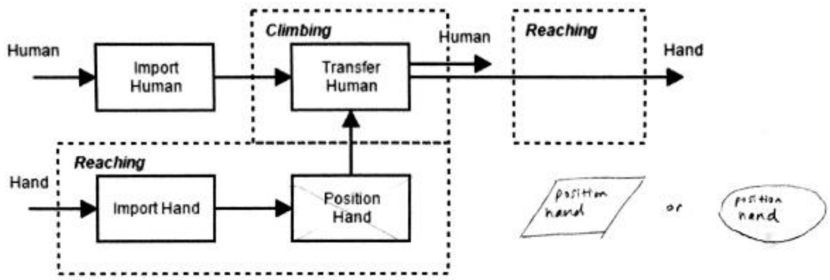
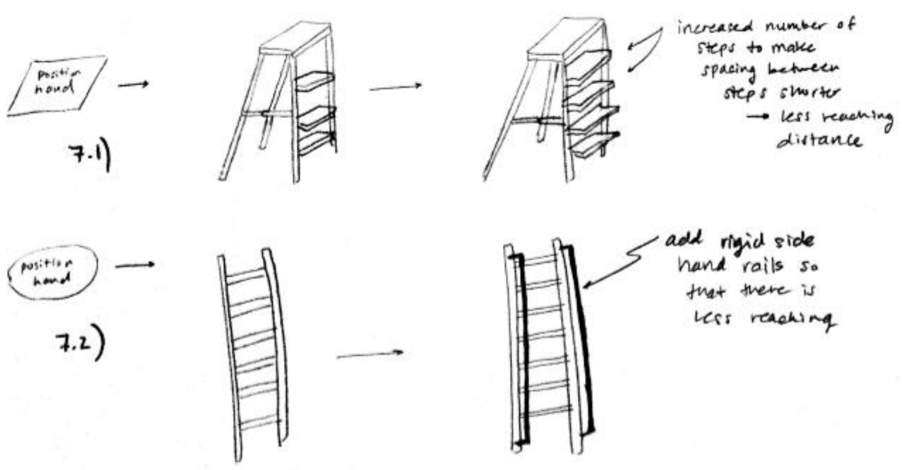


Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the typical ladder as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).



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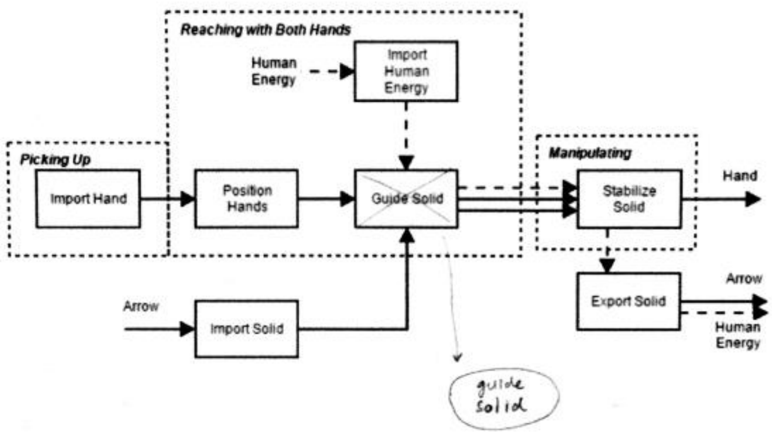
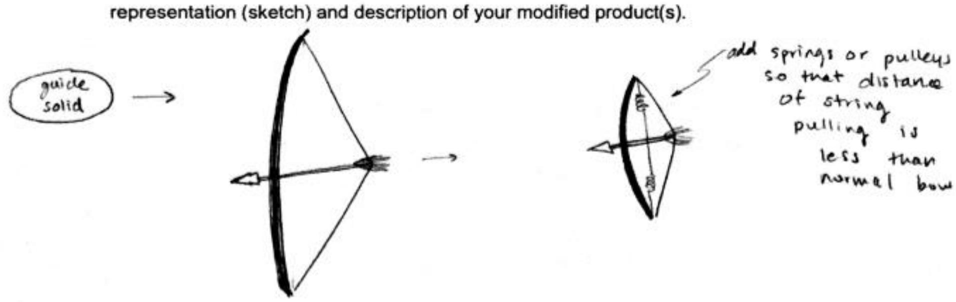


Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bow as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).



Case 22: Grocery Bags

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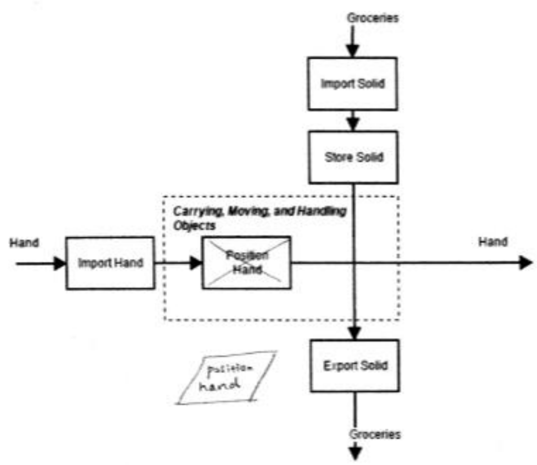
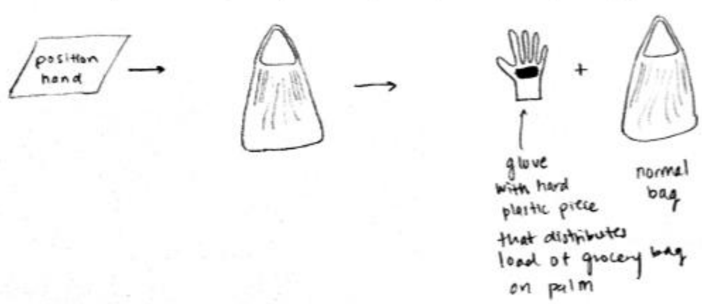


Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the grocery bags as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).



Case 32: Car Doors

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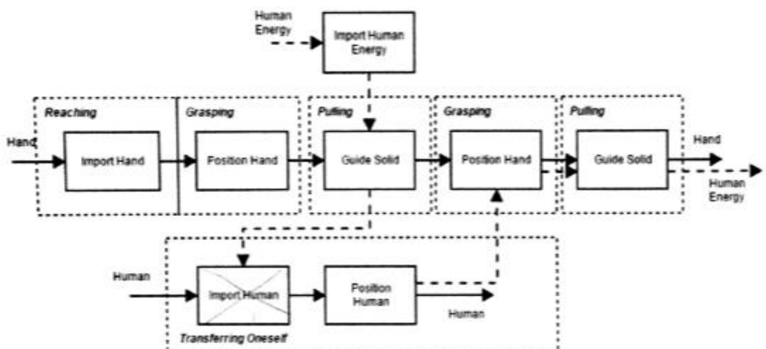
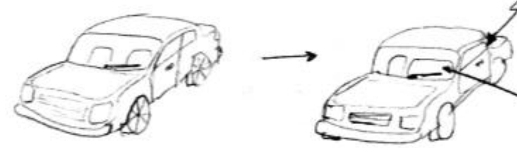


import human or import human

Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the car door as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

import human →



32.1)

bigger door for more easy accessibility

bigger seat for more easy entrance

import human →

32.2)

normal car seat

Motors that move seat out of car so user can sit, then motors move back in

Case 4: Bottle Cap

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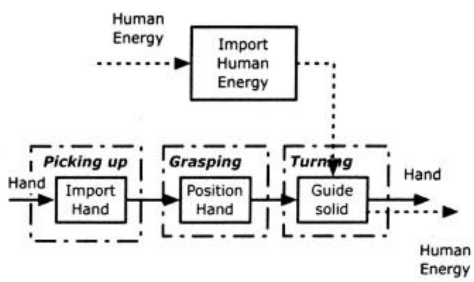


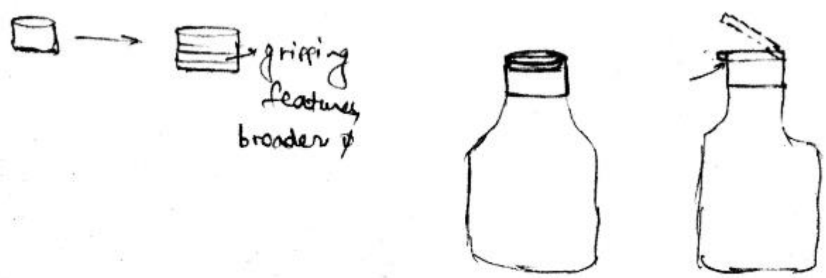
Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bottle cap as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Design Rules:

4.1) - Position Hand undergoes a parametric change. The size of the bottle cap can be increased in diameter.
Or the bottle cap can also undergo a functional change.

Case 4: Bottle Cap (continued)

4.2) The guide solid function (turning) can be changed functionally. Instead of using a twisting motion, the bottle opener can be popped up.



Case 7: Typical Ladder

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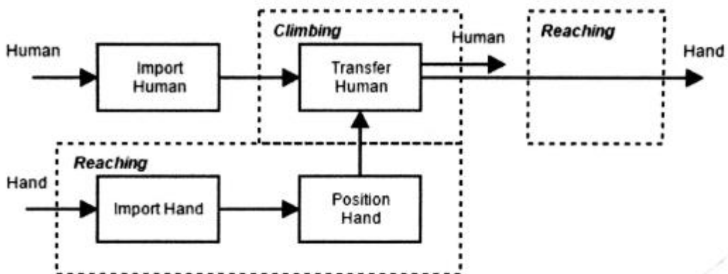


Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the typical ladder as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Design Principles :

The positioning Hand-function can undergo a parametric change.

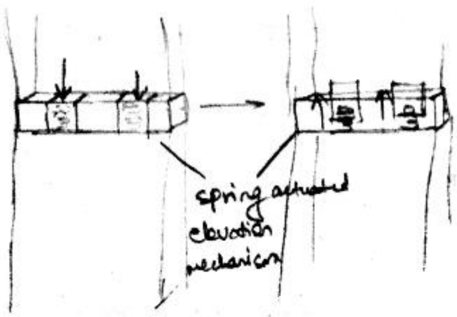
7.1) Most of the typical ladders just have the ladder sideprofiles which are grasped by the users as they climb up. People with physical impairments may need additional gripping handles, or probably some side railings to lean on & support their body weight if needed.

7.2) The locomotive function of the human climbing up can undergo a morphological change. Instead of pulling the entire body weight up, the ladder design can be changed such that is easier

Case 7: Typical Ladder (continued)

to push using the lower extremities.

7.2, cont'd) Bicycle pedal type features can be provided with springs at the bottom which provide elevation when the user steps on them & presses some switch | simple actuation mechanism of a sort.



Case 8: Bow

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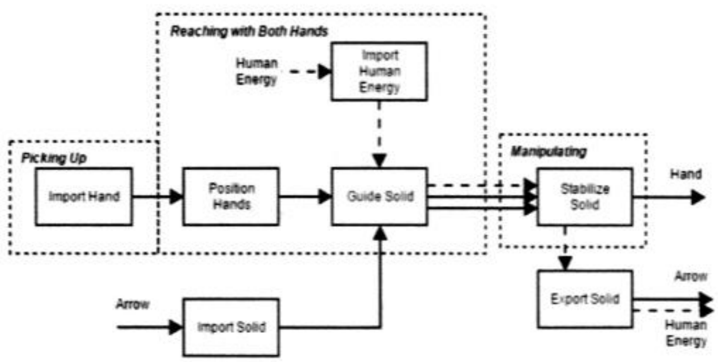


Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bow as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Design Principles :

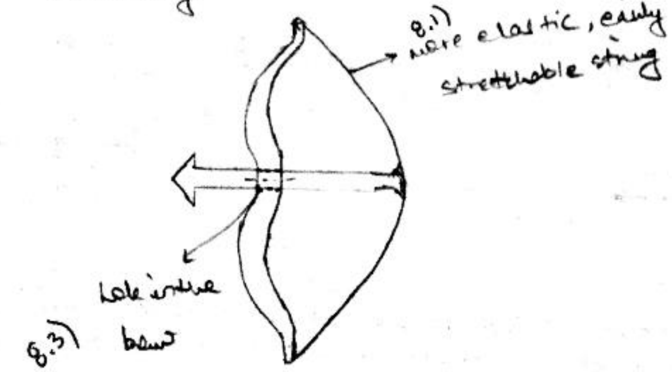
8.1) Reaching with both hands undergoes a morphological change. In that, while positioning hand, a parametric change can be made to string that is to be pulled back, making it more elastic.

8.2) While guiding the arrow / shooting it, some appended features may be provided at the bow where the other hand is holding it, essentially some springs which accentuate the forward push force applied to the arrow.

Case 8: Bow (continued)

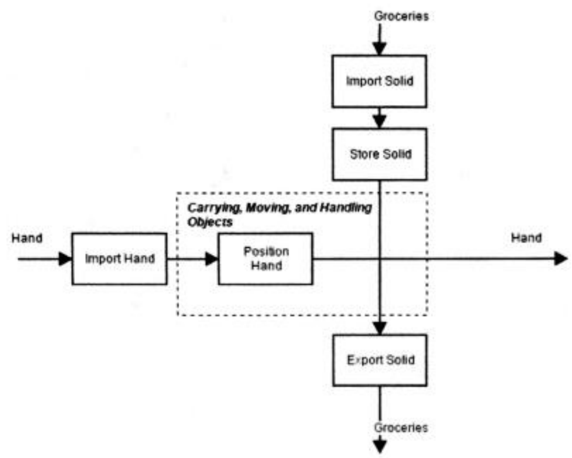
Manipulating function undergoes a parametric change.

8.3) Additional features can be provided in the bow. The arrow can actually be made to pass through a hole in the bow. This provides additional guide to the arrow as well as keeps it stable before launching.



Case 22: Grocery Bags

In order to make environments and products more accessible to all users, designers should consider changes to how a user positions their hands on the product to move or otherwise handle the object. Users with upper body disabilities will have difficulty grasping or carrying certain shapes of objects, so designers should consider changes in order to develop more inclusive products. A relevant product is a typical grocery bag. Users with hand impairments may not have the dexterity or strength required to properly carry the bag. Handling the grocery bag may be difficult for various reasons. The handles are narrow and do not provide much room for gripping, likewise the handles are not made of substantial material and may deform, tear, or cut into the user's hand.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the grocery bags as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Design Principles:

Position Hand can undergo a parametric change.
Instead of providing plastic bag handles, paper or
22.1) fabric handles can be used. These are softer ... on hands in the sense they won't cut it. Also, they provide additional grip.
They can also be made broader for easier grasp & preventing tearing.

Alternatively, a hoop & loop kind of arrangement can be used.
22.2) Users can be provided with a band which can worn on the palms containing one side of Velcro strip. The bag handles constitute the other Velcro band end. While grasping, additional friction is provided by these Velcro strips & thus reduce the force exerted by user.

Hoop & loop type strap worn by user with other mating part stitched on the bag.

Case 32: Car Doors

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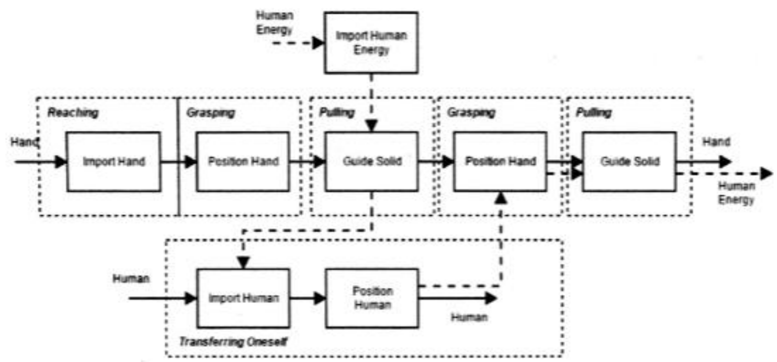

Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the car door as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Design Rules:

Grasping (position hand) may undergo a parametric change. Both car door handles (inside as well as outside) can be made broder for the user to grasp easily.

Pulling (guide solid) while opening & closing the door can undergo either parametric or morphological change.

Case 32: Car Doors (continued)

32.1) In parametric modification, additional mechanisms like springs or fluid pressure can be provided along the door hinges that reduce the force required by the user to open / close.

32.2) Morphologically, the entire pulling action can be replaced by "no action" by using switches / button activated mechanisms that automatically open / close the door.

15

Case 4: Bottle Cap

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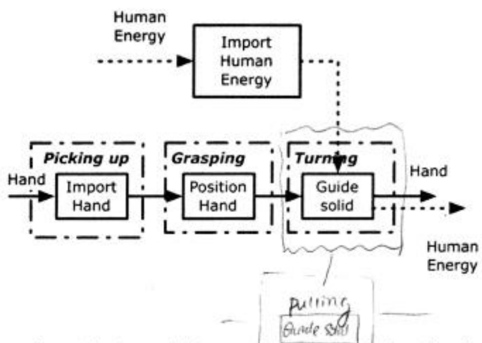

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Case 7: Typical Ladder

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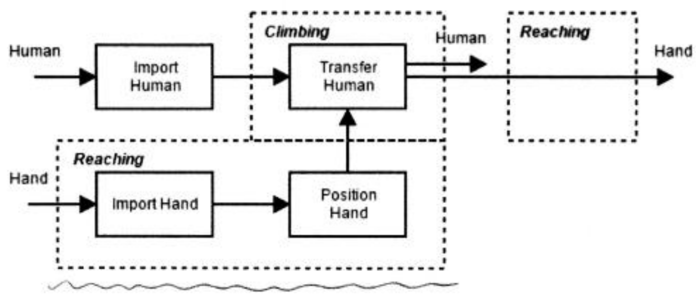
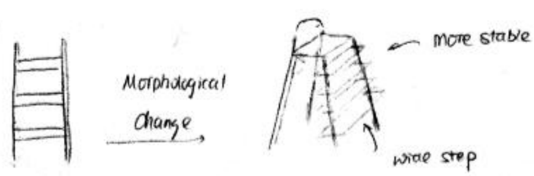


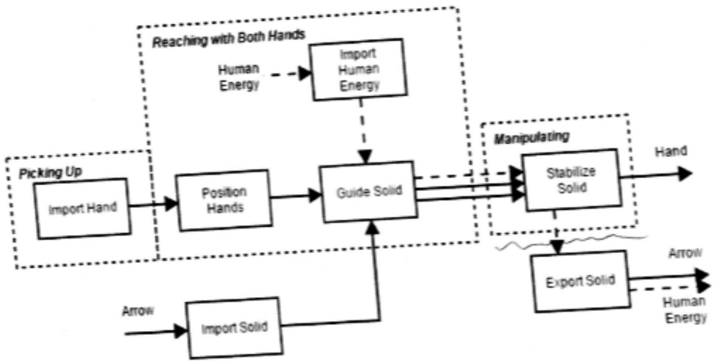
Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the typical ladder as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Instead of the single-structure ladder we can use another type to satisfy people scaling the ladder regardless of their reach capabilities.



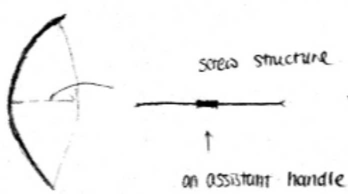
Case 8: Bow

Users with physical impairments have difficulty exerting force with their arms extended. Consider the typical bow. While not typically associated with disabled users, archery is a sport many enjoy. Less able users would have difficulty drawing and steadying a typical bow, as they may not be strong enough to exert force with an outstretched arm.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bow as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

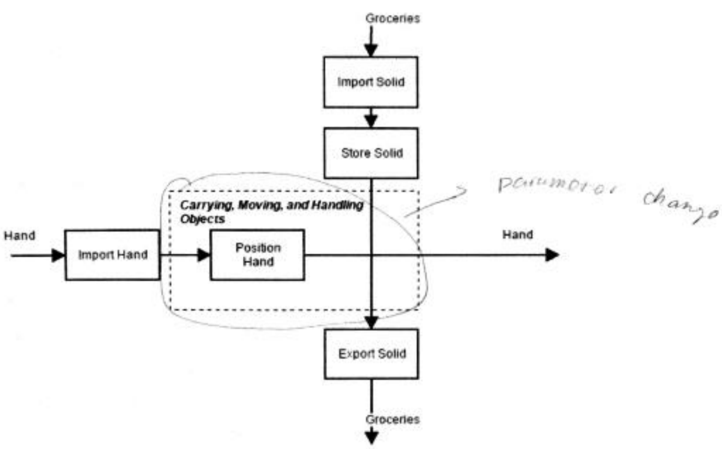
Some people have difficulty using two hands to stabilize solid, so the design aims to keep the bow states using some other tools. Just like add a stabilizer on the bow when you insert the



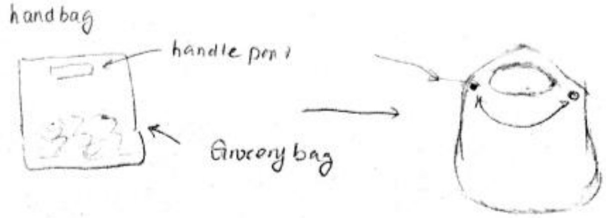
to fix the position of the bow when ~~it~~ exporting solid. there is a button to press the arrow will be exert

Case 22: Grocery Bags

In order to make environments and products more accessible to all users, designers should consider changes to how a user positions their hands on the product to move or otherwise handle the object. Users with upper body disabilities will have difficulty grasping or carrying certain shapes of objects, so designers should consider changes in order to develop more inclusive products. A relevant product is a typical grocery bag. Users with hand impairments may not have the dexterity or strength required to properly carry the bag. Handling the grocery bag may be difficult for various reasons. The handles are narrow and do not provide much room for gripping, likewise the handles are not made of substantial material and may deform, tear, or cut into the user's hand.



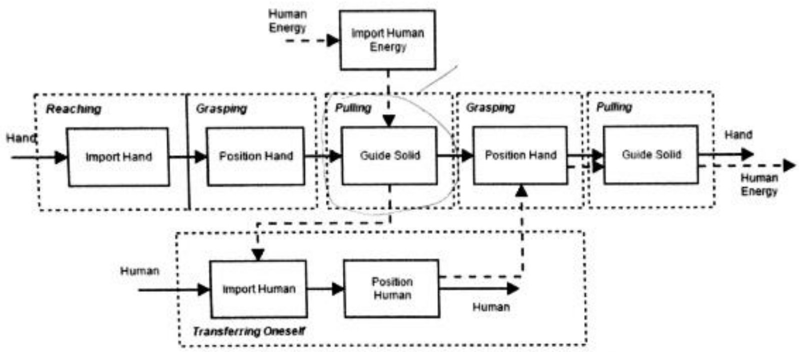
Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the grocery bags as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).



Change the handler's space more smooth. more spce if the grocery is too heavy can use the snap-fastener to increase the handle part to increase the stability ~~and~~

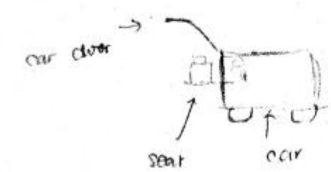
Case 32: Car Doors

Designers should consider users with diminished mobility when designing the access points for products and environments. Users with mobility impairments will have trouble transferring themselves into the car through the car door unassisted, as they may lack the coordination or strength necessary to pull themselves into the car. The figure below shows the actionfunction diagram for a typical car door.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the car door as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

people ~~who~~ have difficulty in pulling themselves into the car
so who change the design to make them easier into the car



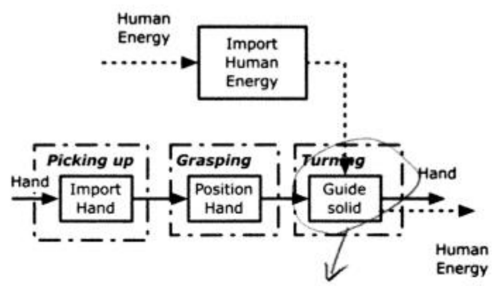
morphological change

with the door open upside down
it will provide more space for ~~people~~ users with mobility impairment
the chair/seats for these people can move outside a little bit automatically ~~[illegible]~~
The users can control these system automatically without insert lots of human energy

Case 4: Bottle Cap

Users with diminished dexterity may have difficulties utilizing a pincer grip to grasp objects, as is necessary when turning an object. Designers should consider modifying products that require turning to instead utilize a different user activity. A classic example of a product that requires gripping and turning is a twist-off bottle cap, such as one would find on a plastic water bottle. The actionfunction diagram for a plastic water bottle cap is pictured below.

Typical bottle caps are threaded onto a receiving thread on the bottle, a cheap and reusable way of sealing the bottle. In developing a more inclusive product, we must also consider the marketability of the resulting product. Any new inclusive design should avoid increasing the cost or complexity of the system, so as to not inhibit its use.

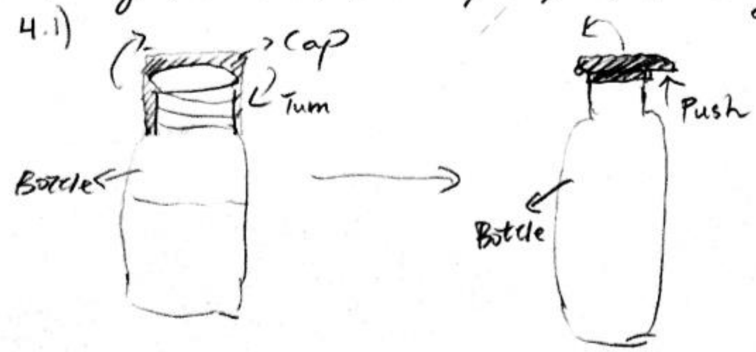


. Morphological change → Pushing with hands

Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bottle cap as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

① Turning → Guide solid → Morphological → Pushing with hands

4.1)

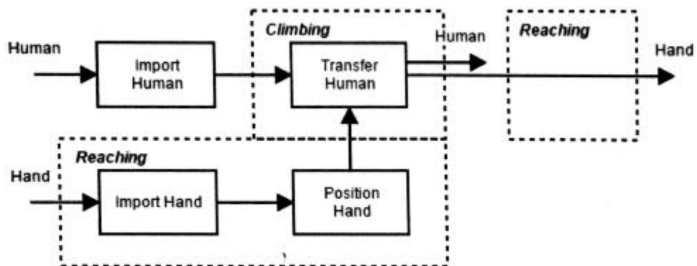


Case 4: Bottle Cap (continued)

② Turning → Guild Solid → Morphological → Pushing with hands
4.2)

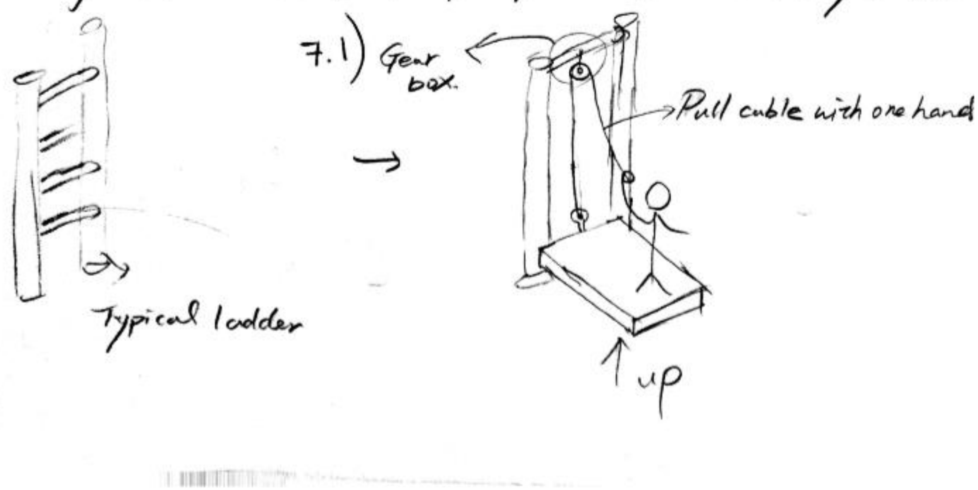
Case 7: *Typical Ladder*

Users with physical impairments may have reduced reach when compared to able users. Consider the typical ladder, which requires users to reach and exert force with outstretched arms when climbing. In order to make the ladder more inclusive, modifications should allow users to scale the ladder regardless of their reach capabilities. The actionfunction diagram for a typical ladder is pictured below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the typical ladder as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

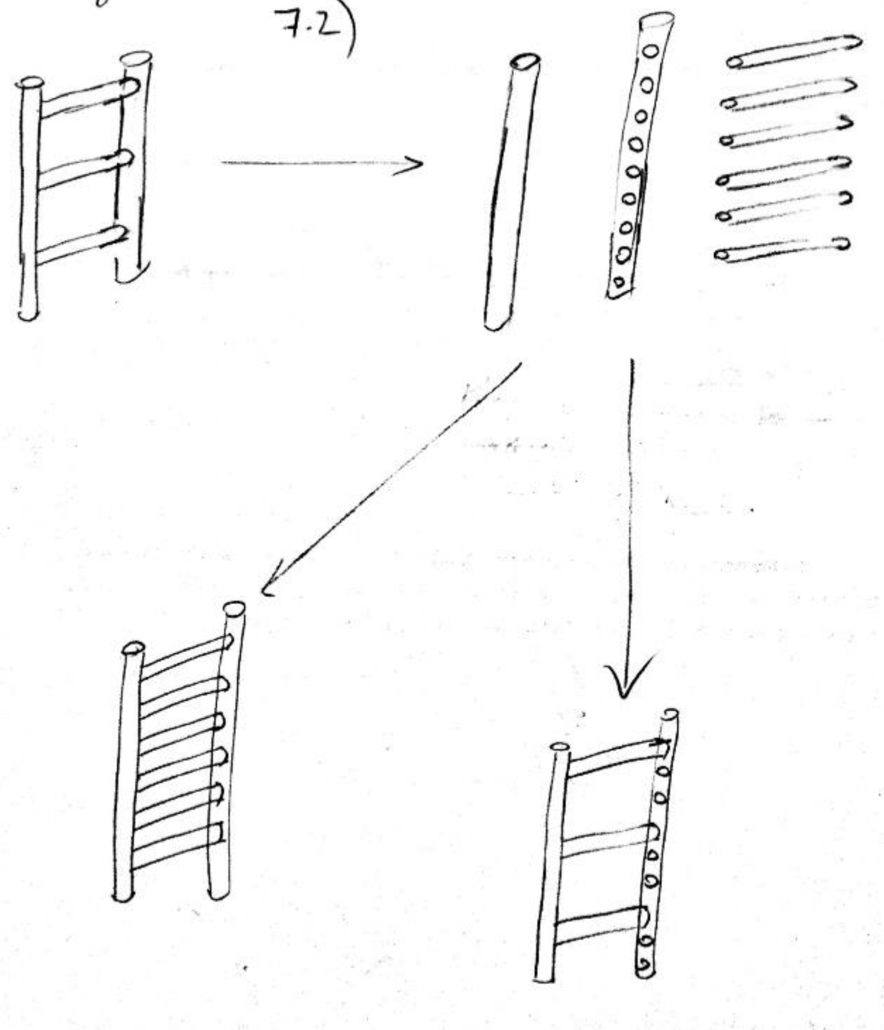
Reaching → Position hand → Morphological → Reach with single arm



Case 7: Typical Ladder (continued)

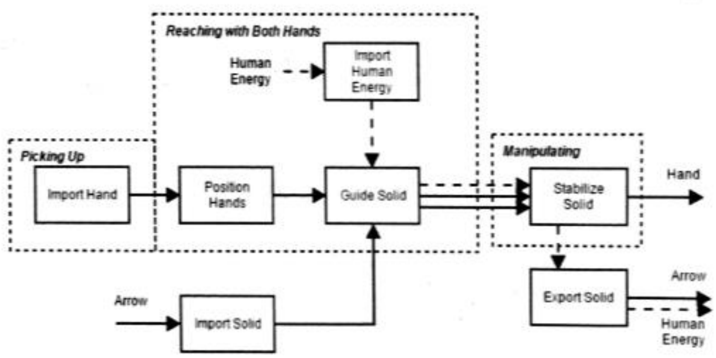
Reaching → Position Hand → Parametric → Basics

7.2)



Case 8: Bow

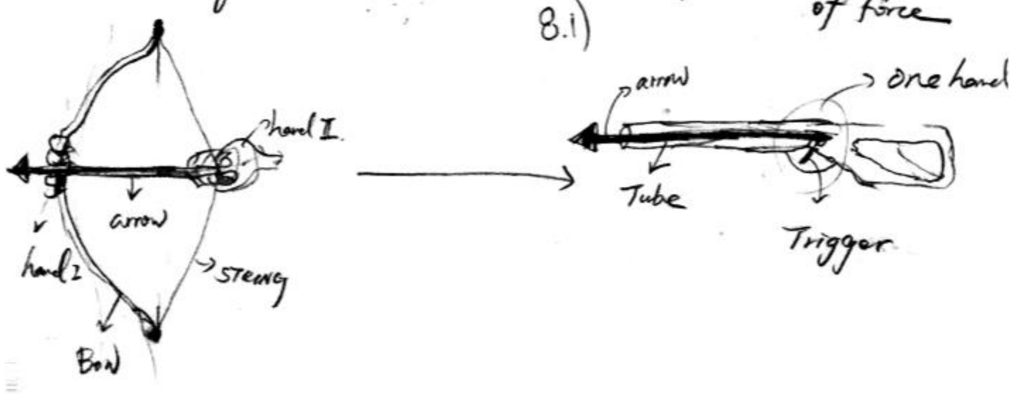
Users with physical impairments have difficulty exerting force with their arms extended. Consider the typical bow. While not typically associated with disabled users, archery is a sport many enjoy. Less able users would have difficulty drawing and steadying a typical bow, as they may not be strong enough to exert force with an outstretched arm.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bow as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Manipulating → Stabilize Solid → Mophological → Easier One application of force

8.1)

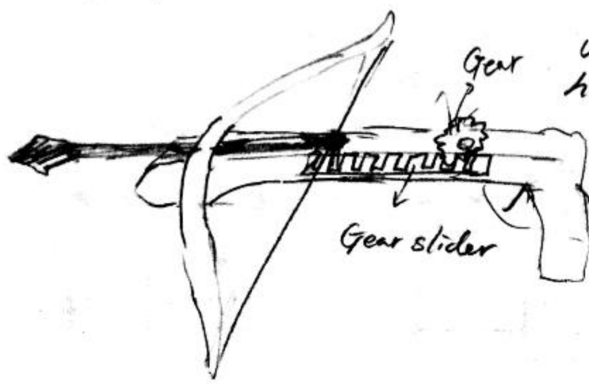


Case 8: Bow (continued)

(7)

Reaching → Guild Solid → Morphological → Not exerting force with arm outstre

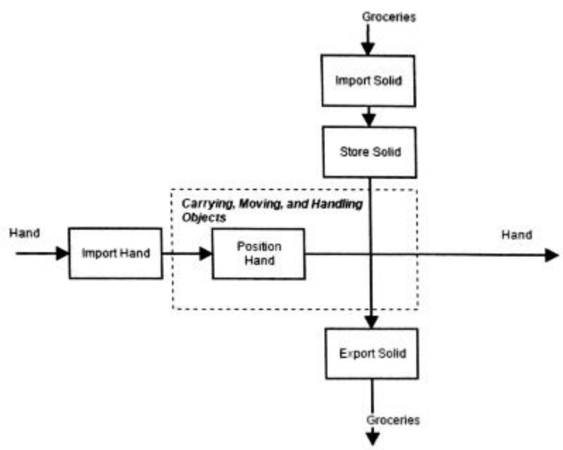
(8.2)



use motor to replace human energy.

Case 22: Grocery Bags

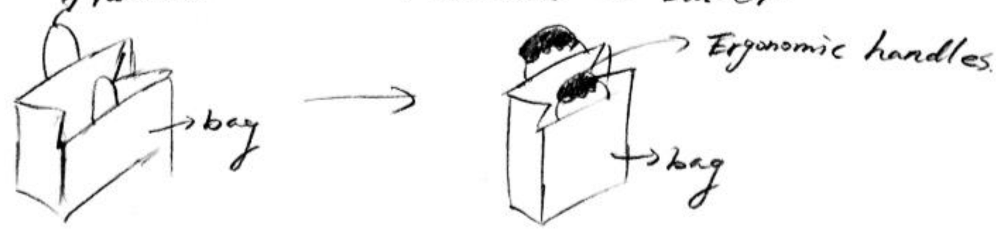
In order to make environments and products more accessible to all users, designers should consider changes to how a user positions their hands on the product to move or otherwise handle the object. Users with upper body disabilities will have difficulty grasping or carrying certain shapes of objects, so designers should consider changes in order to develop more inclusive products. A relevant product is a typical grocery bag. Users with hand impairments may not have the dexterity or strength required to properly carry the bag. Handling the grocery bag may be difficult for various reasons. The handles are narrow and do not provide much room for gripping, likewise the handles are not made of substantial material and may deform, tear, or cut into the user's hand.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the grocery bags as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

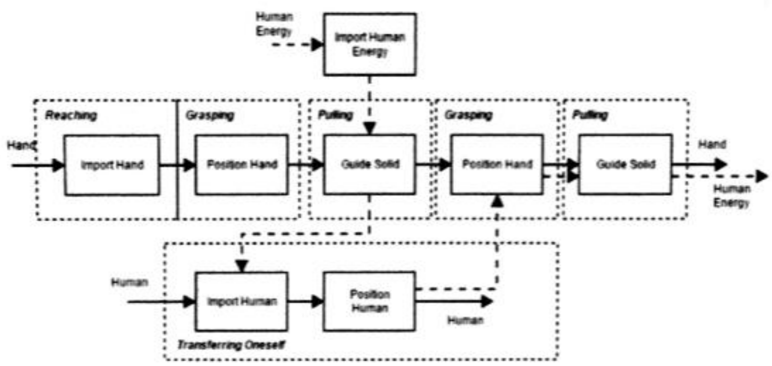
Carrying, Moving, and Handling → Position hand →

handles Parametric → Easier



Case 32: Car Doors

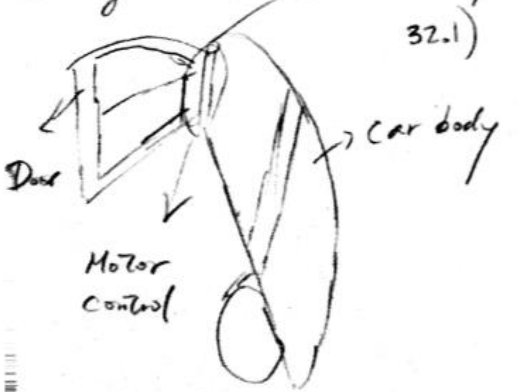
Designers should consider users with diminished mobility when designing the access points for products and environments. Users with mobility impairments will have trouble transferring themselves into the car through the car door unassisted, as they may lack the coordination or strength necessary to pull themselves into the car. The figure below shows the actionfunction diagram for a typical car door.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the car door as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Pulling → Guide Solid → Morphological → No activities.

32.1)

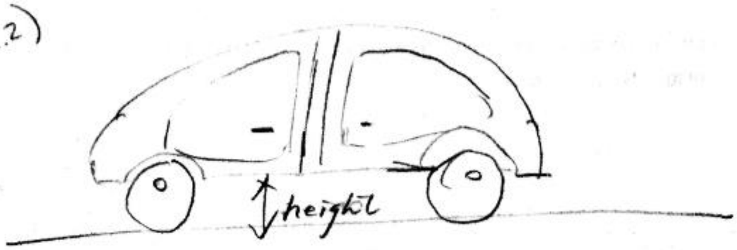


Use motor to open & close the door.

Case 32: Car Doors (continued)

Transfering oneself → Import Human → Parametric → Easier

32.2)

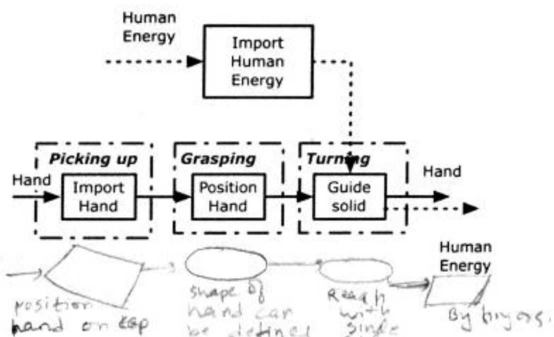


Reduce the height between the car body and ground, so people could get in the car easierly.

Case 4: Bottle Cap

Users with diminished dexterity may have difficulties utilizing a pincer grip to grasp objects, as is necessary when turning an object. Designers should consider modifying products that require turning to instead utilize a different user activity. A classic example of a product that requires gripping and turning is a twist-off bottle cap, such as one would find on a plastic water bottle. The actionfunction diagram for a plastic water bottle cap is pictured below.

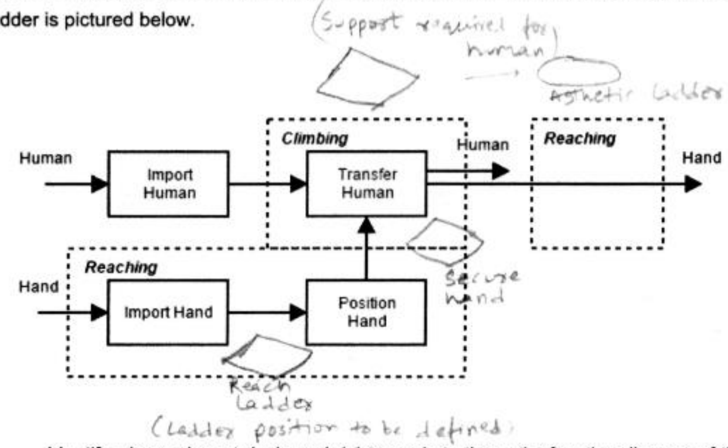
Typical bottle caps are threaded onto a receiving thread on the bottle, a cheap and reusable way of sealing the bottle. In developing a more inclusive product, we must also consider the marketability of the resulting product. Any new inclusive design should avoid increasing the cost or complexity of the system, so as to not inhibit its use.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bottle cap as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Case 7: Typical Ladder

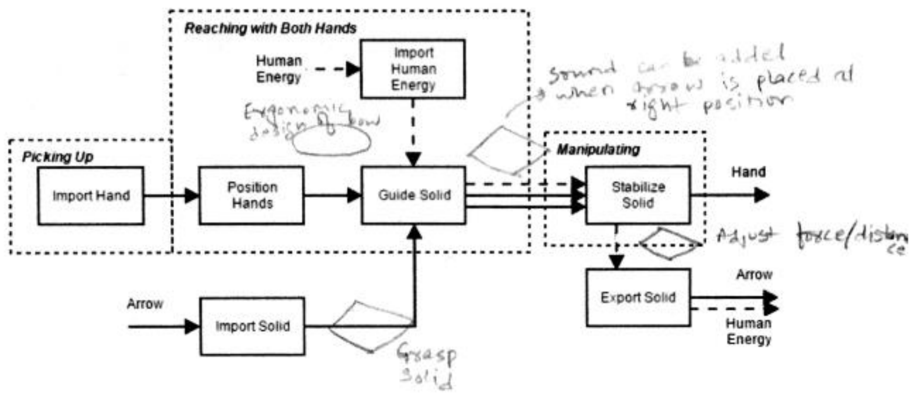
Users with physical impairments may have reduced reach when compared to able users. Consider the typical ladder, which requires users to reach and exert force with outstretched arms when climbing. In order to make the ladder more inclusive, modifications should allow users to scale the ladder regardless of their reach capabilities. The actionfunction diagram for a typical ladder is pictured below.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the typical ladder as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Case 8: Bow

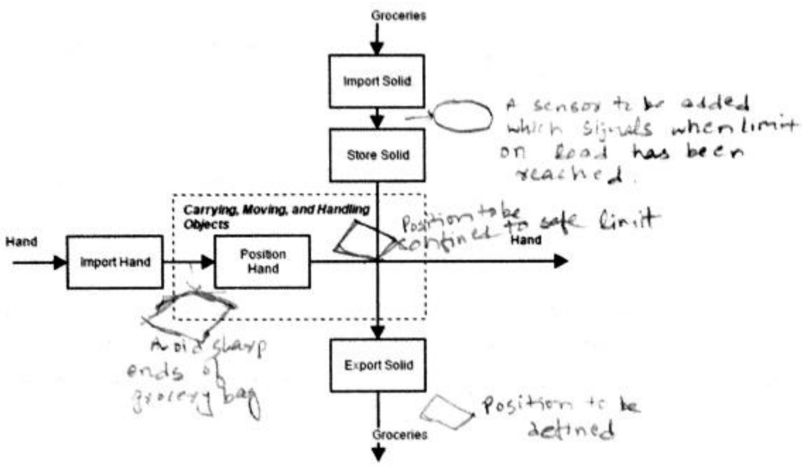
Users with physical impairments have difficulty exerting force with their arms extended. Consider the typical bow. While not typically associated with disabled users, archery is a sport many enjoy. Less able users would have difficulty drawing and steadying a typical bow, as they may not be strong enough to exert force with an outstretched arm.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bow as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Case 22: Grocery Bags

In order to make environments and products more accessible to all users, designers should consider changes to how a user positions their hands on the product to move or otherwise handle the object. Users with upper body disabilities will have difficulty grasping or carrying certain shapes of objects, so designers should consider changes in order to develop more inclusive products. A relevant product is a typical grocery bag. Users with hand impairments may not have the dexterity or strength required to properly carry the bag. Handling the grocery bag may be difficult for various reasons. The handles are narrow and do not provide much room for gripping, likewise the handles are not made of substantial material and may deform, tear, or cut into the user's hand.

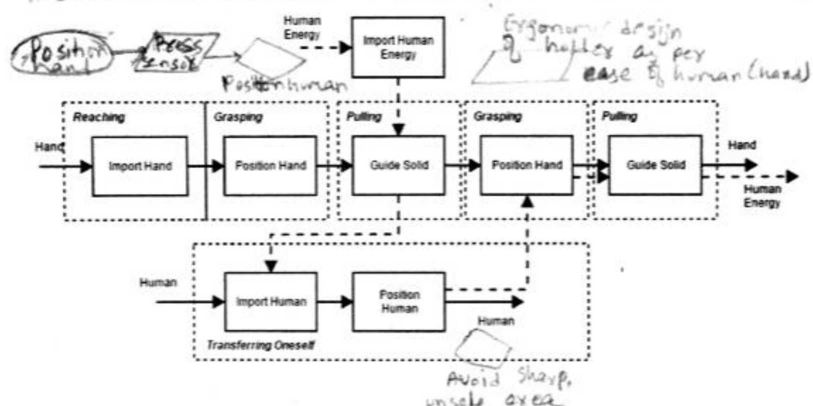


Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the grocery bags as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Case 32: Car Doors

Designers should consider users with diminished mobility when designing the access points for products and environments. Users with mobility impairments will have trouble transferring themselves into the car through the car door unassisted, as they may lack the coordination or strength necessary to pull themselves into the car. The figure below shows the actionfunction diagram for a typical car door.

A sensor can be added on car door. On pressing it, the door opens.



Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the car door as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

Case 4: Bottle Cap

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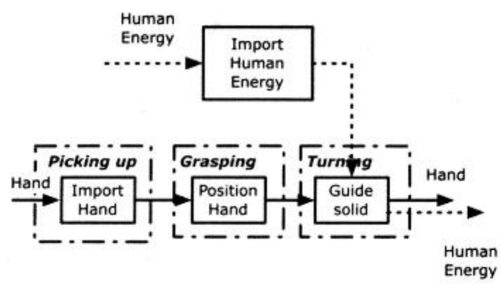
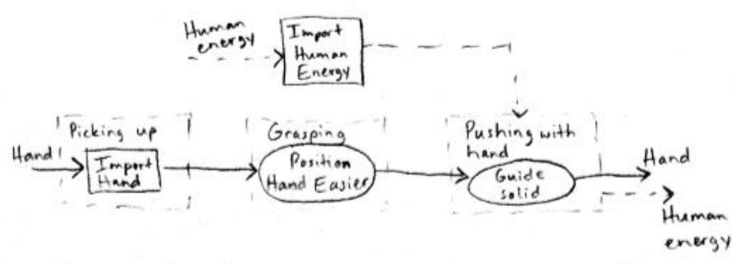
Typical bottle caps are threaded onto a receiving thread on the bottle, a cheap and reusable way of sealing the bottle. In developing a more inclusive product, we must also consider the marketability of the resulting product. Any new inclusive design should avoid increasing the cost or complexity of the system, so as to not inhibit its use.



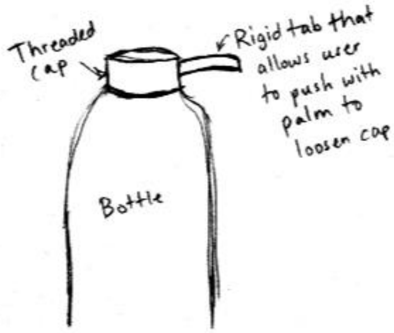
Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bottle cap as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

(Position hand, Grasping) → (Parametric or Morphological, Easier)

(Guide solid, Turning) → (Morphological, Pushing with hand)



Case 4: Bottle Cap (continued)



Case 7: Typical Ladder

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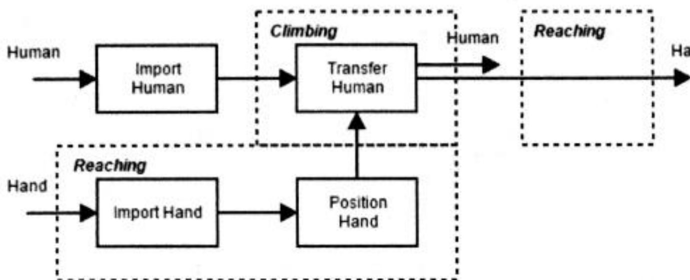
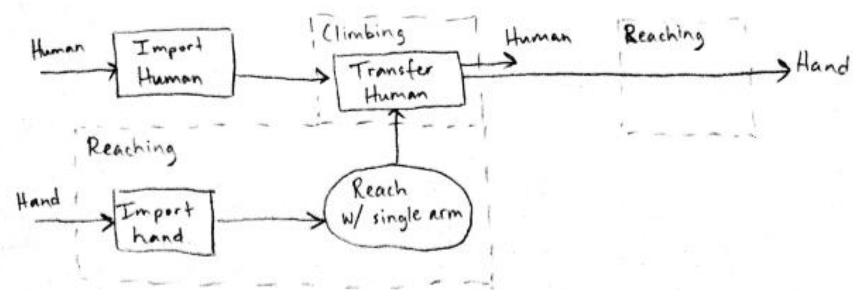
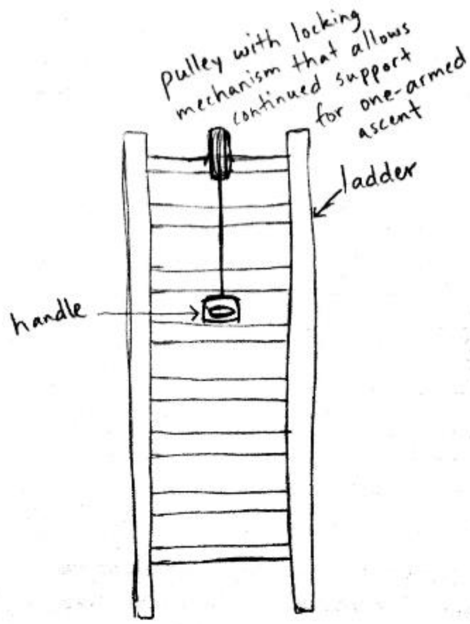


Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the typical ladder as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

(Reaching, Position Hand) ⟶ (Morphological, Reach with single arm) ?



Case 7: *Typical Ladder* (continued)



Case 8: Bow

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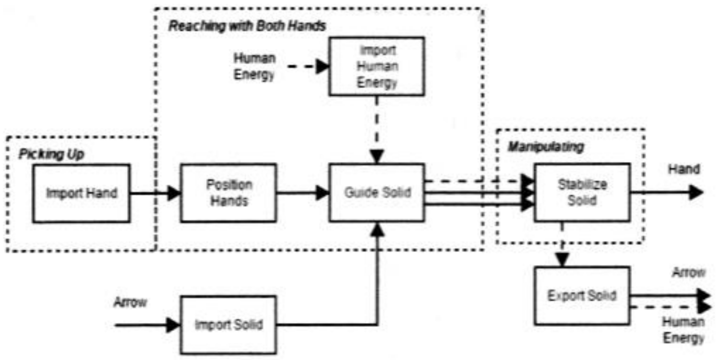
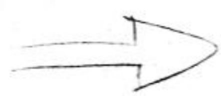


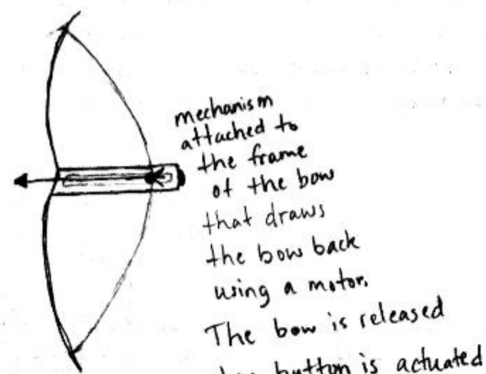
Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the bow as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

(Reaching, Guide Solid) → (Morphological, Not exerting force with arm outstretched)

(Manipulating, StabilizeSolid) → (Morphological, easier (one application of force))



Case 8: Bow (continued)



Case 22: Grocery Bags

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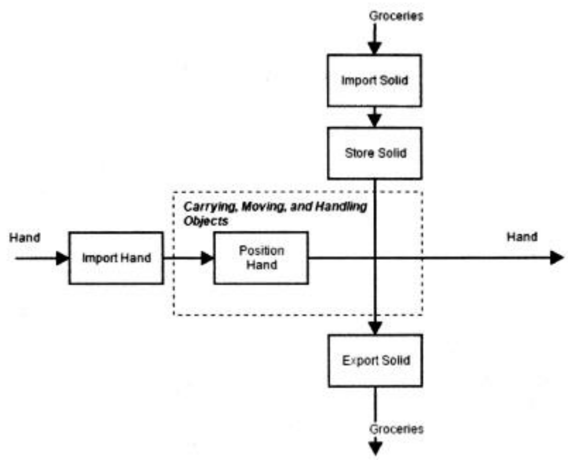
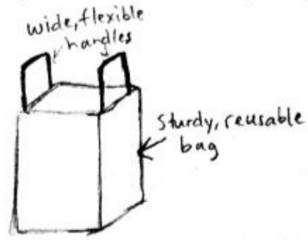


Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the grocery bags as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

((Carrying, Moving, and Handling Objects, Position Hand) → (Parametric, easier)



Case 32: Car Doors

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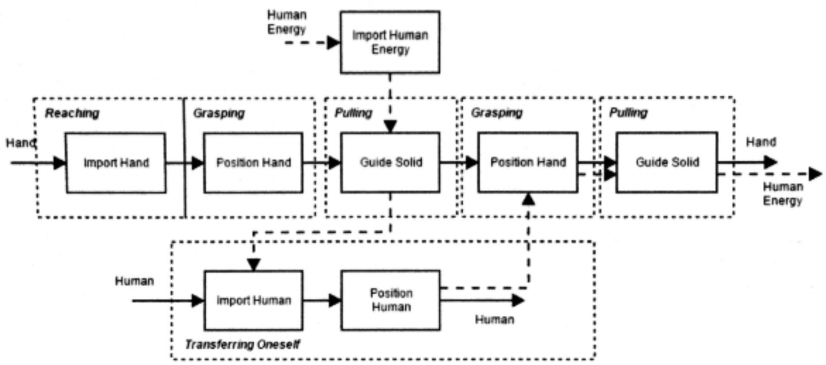


Identify a/any relevant design rule(s) to apply to the actionfunction diagram of the car door as pictured above. After the application of this/these design rules, please develop a physical representation (sketch) and description of your modified product(s).

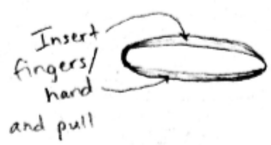
(Grasping, Position Hand) ⟶ (Parametric or Morphological, Easier)

(Pulling, Guide Solid) ⟶ (Parametric, Easier)

(Transferring Oneself, Import human) ⟶ (Parametric, Easier)

1st and 2nd changes regarding door handle...

32.1)



Door handle should be designed in a way that minimal force is required to actuate it.
Door should be designed to open easily and stay open (light weight or

Case 32: Car Doors (continued)

To get into car...

32.2)